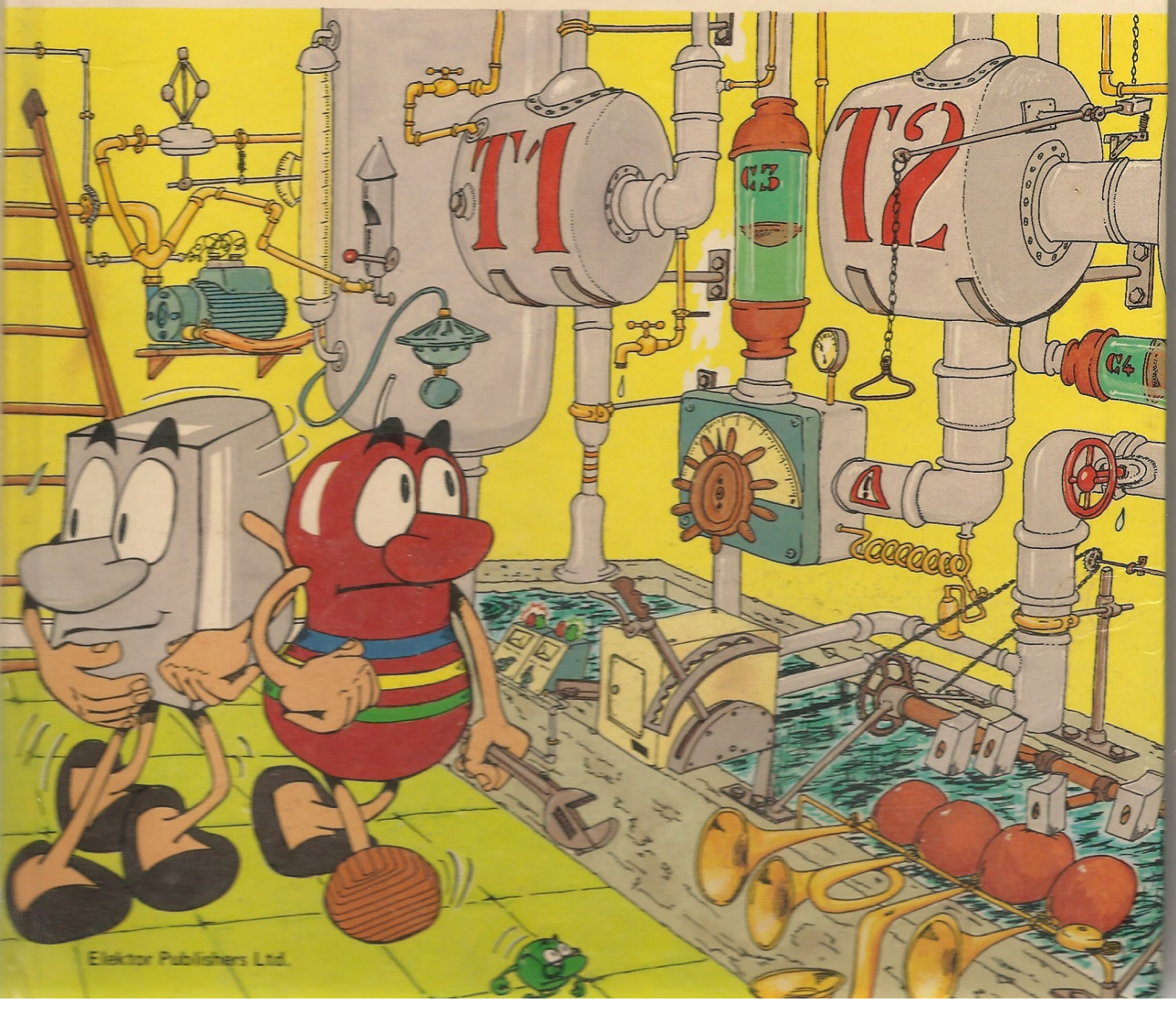
RESI & TRANSI®

BANISH THE MYSTERIES OF ELECTRONICS

Yvan Doffagne
& Yves Caumon



Elektor Publishers Ltd.

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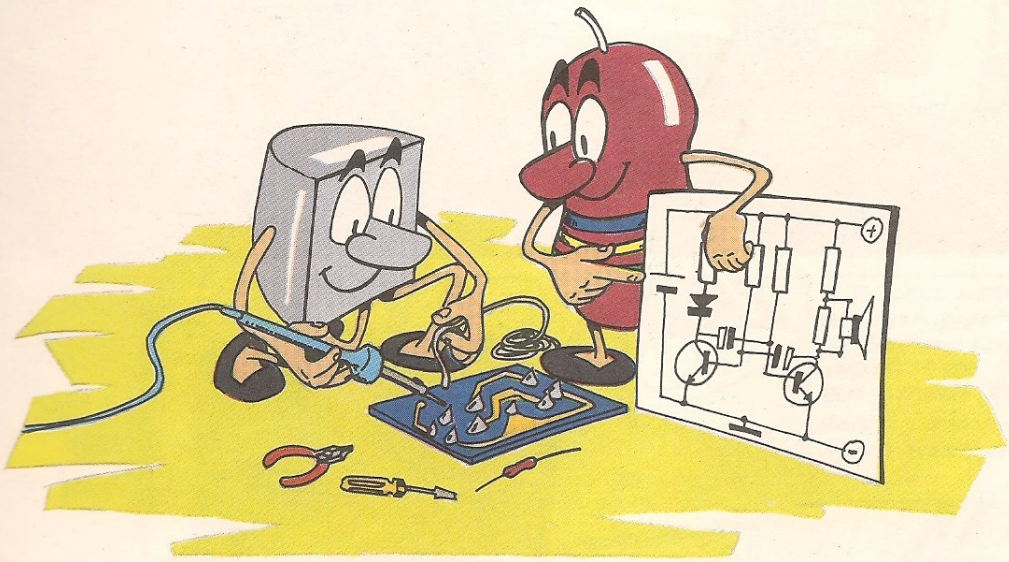
BANISH THE MYSTERIES OF ELECTRONICS

Written and illustrated by Y. Doffagne and Y. Caussin

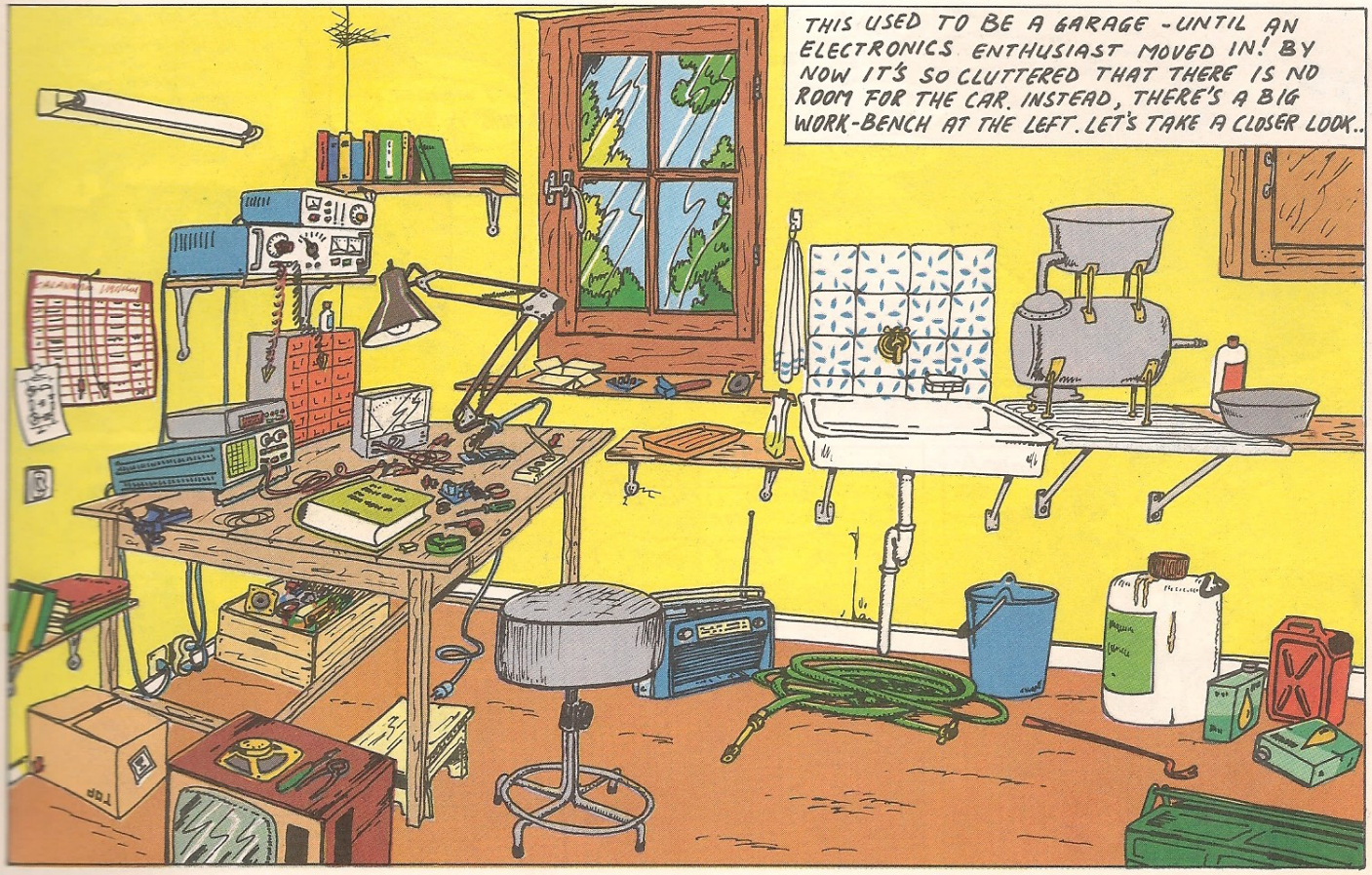


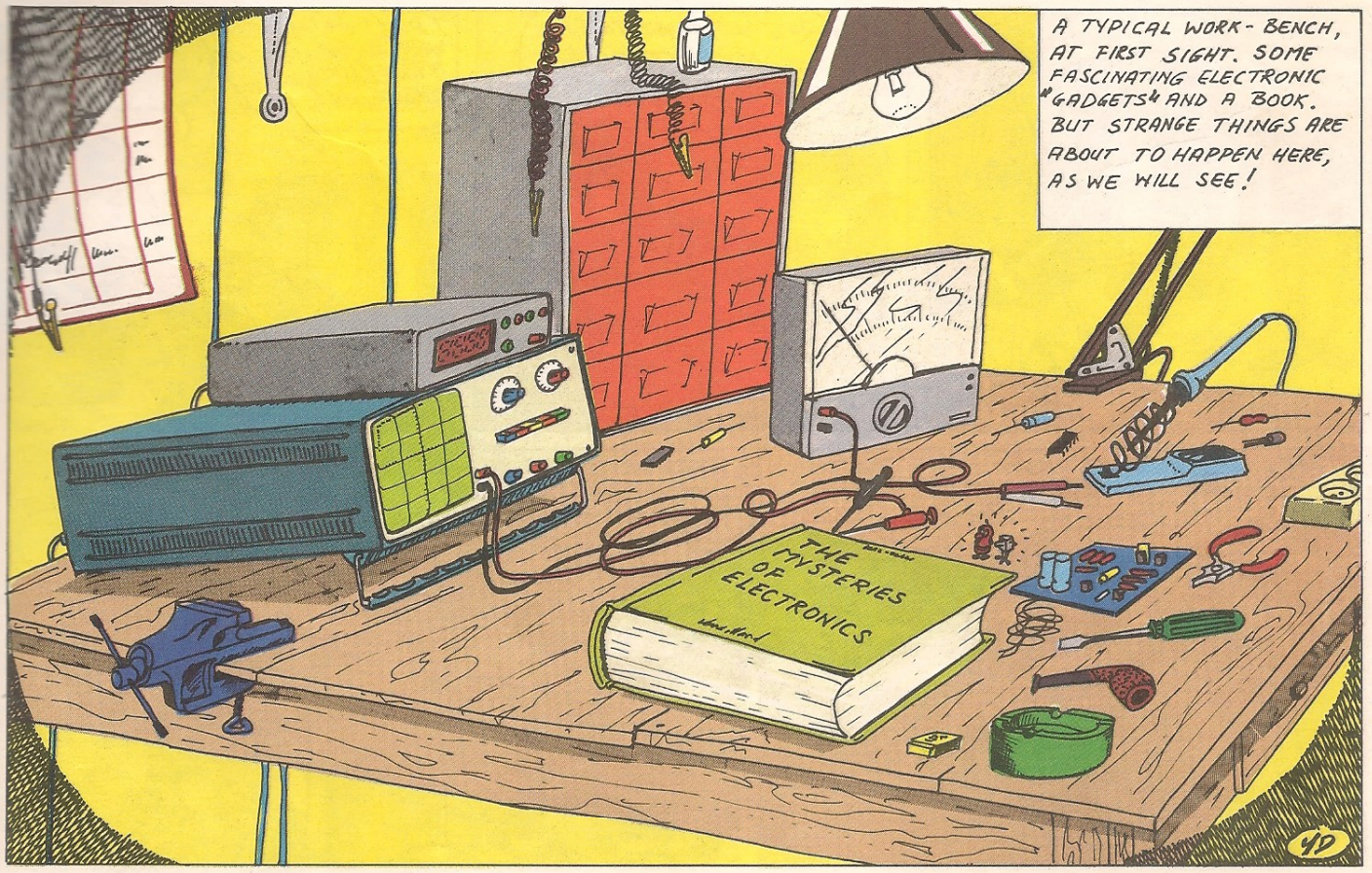
In this adventure, Resi and Transi 'Banish the mysteries of electronics'. In the course of the book, they explain how to build a few practical circuits: a continuity tester, a morse-code beeper and an amplifier. A printed circuit board is included, to simplify the actual construction, as well as an extremely useful gadget, 'THE RESIMETER'.

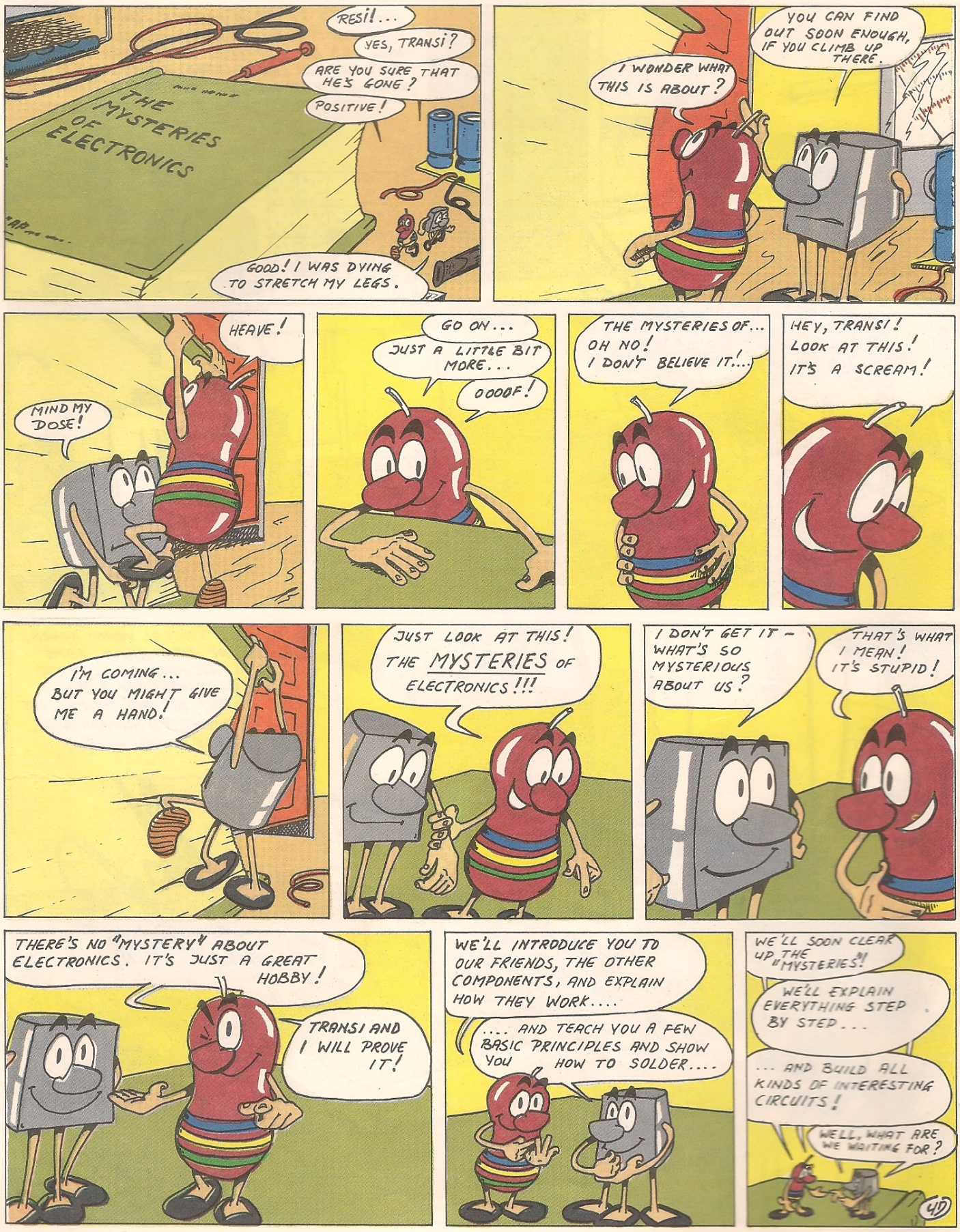
Elektor Publishers Ltd.
Canterbury (U.K.)

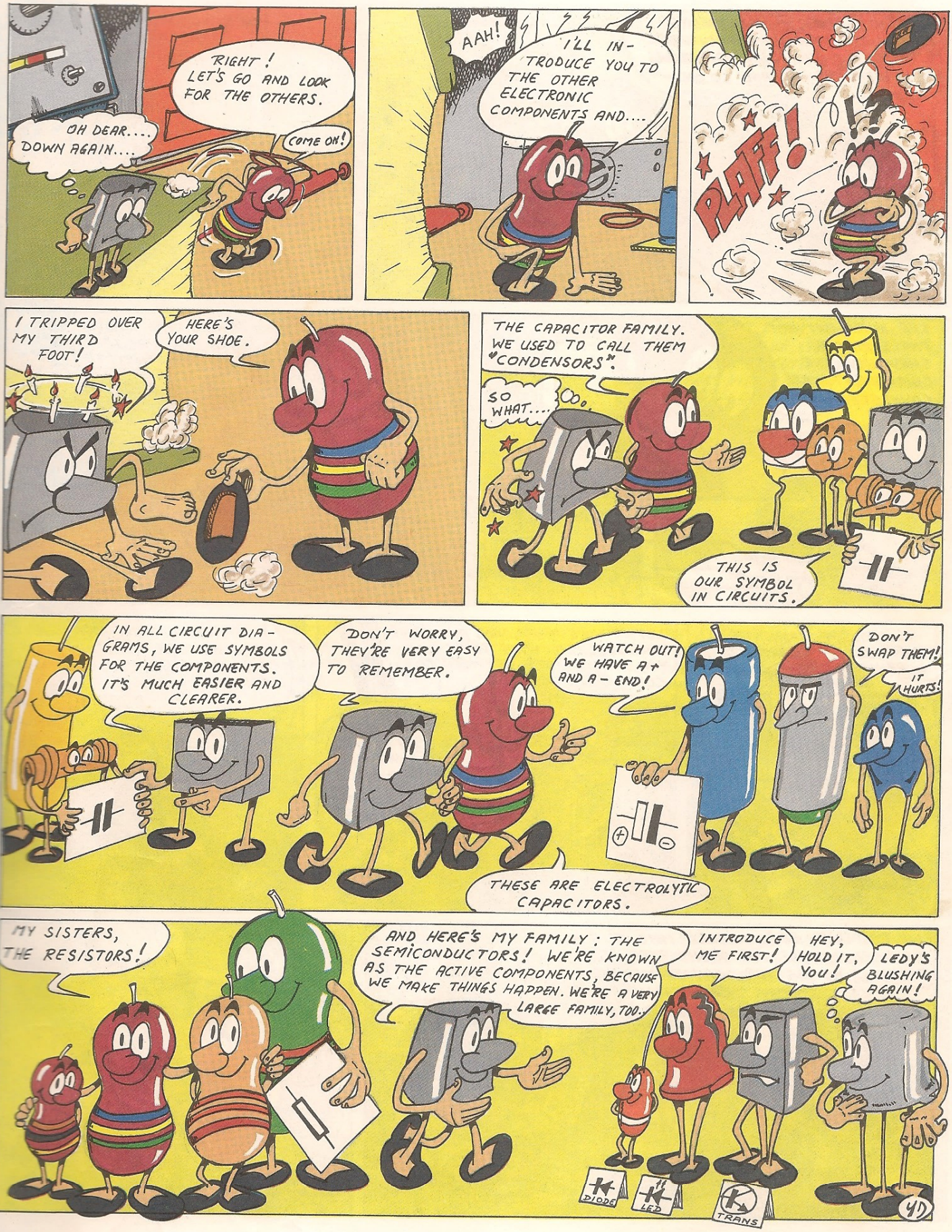
ISBN 0 905705 10 6

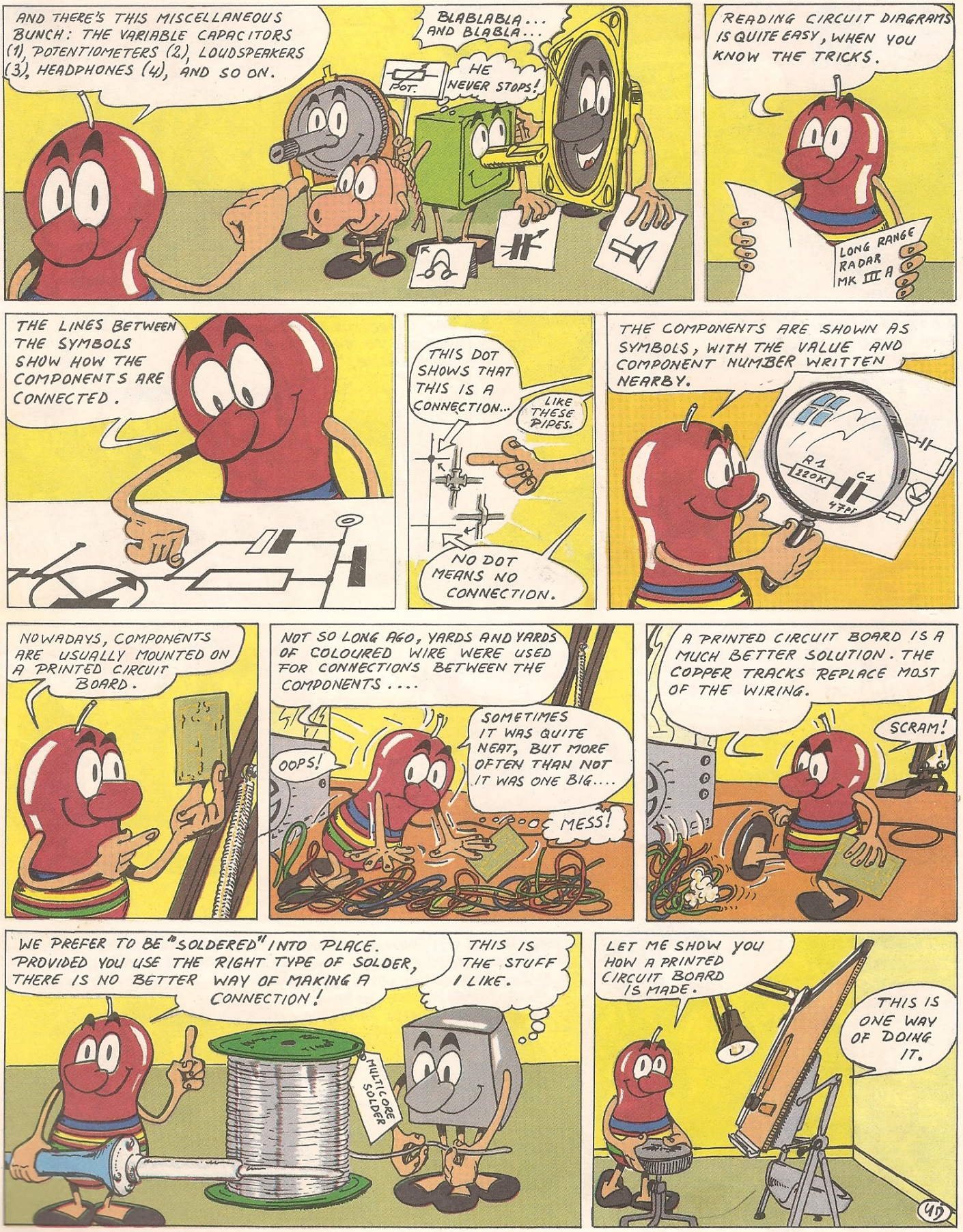
Printed in the Netherlands.

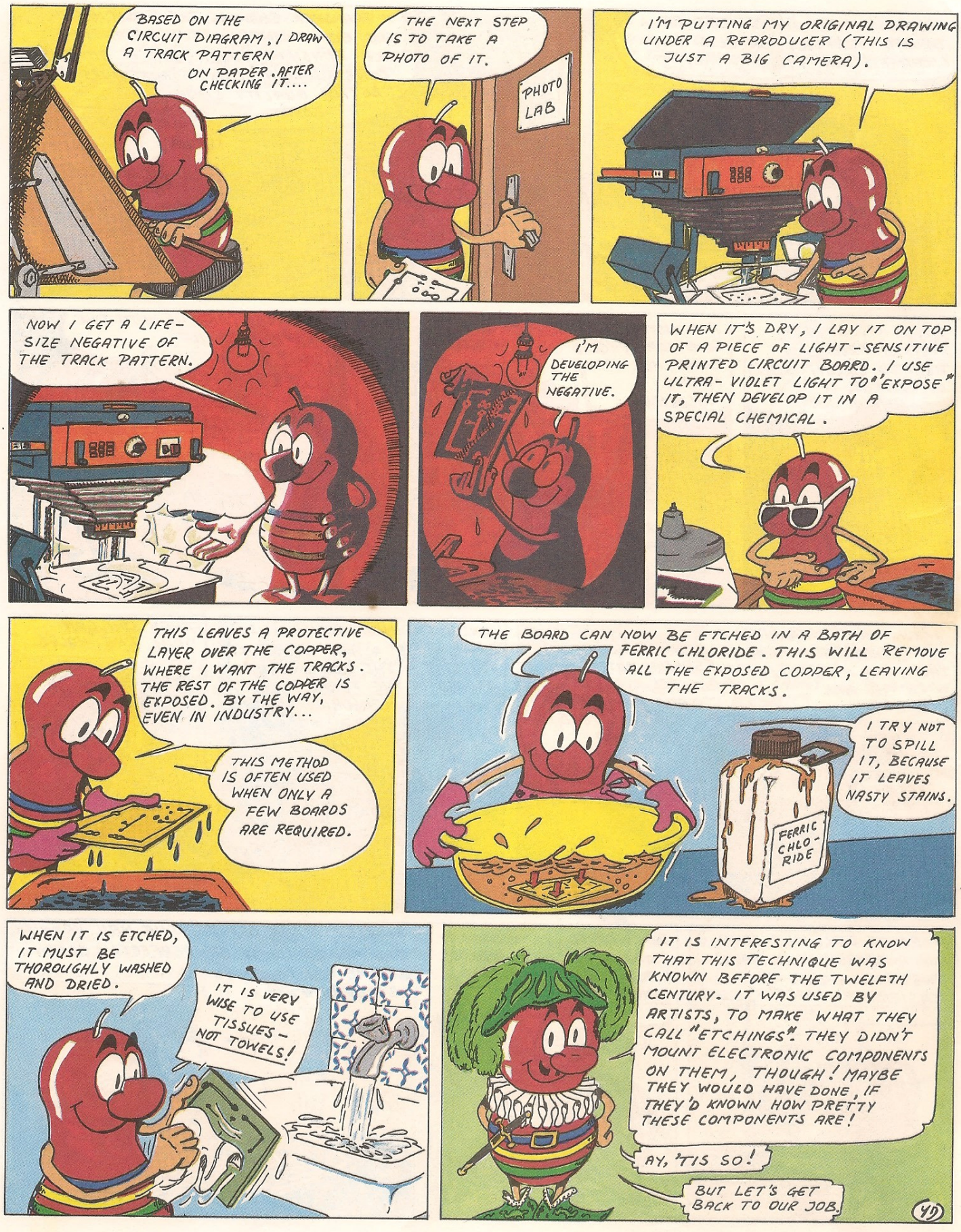

THIS USED TO BE A GARAGE - UNTIL AN ELECTRONICS ENTHUSIAST MOVED IN! BY NOW IT'S SO CLUTTERED THAT THERE IS NO ROOM FOR THE CAR. INSTEAD, THERE'S A BIG WORK-BENCH AT THE LEFT. LET'S TAKE A CLOSER LOOK..

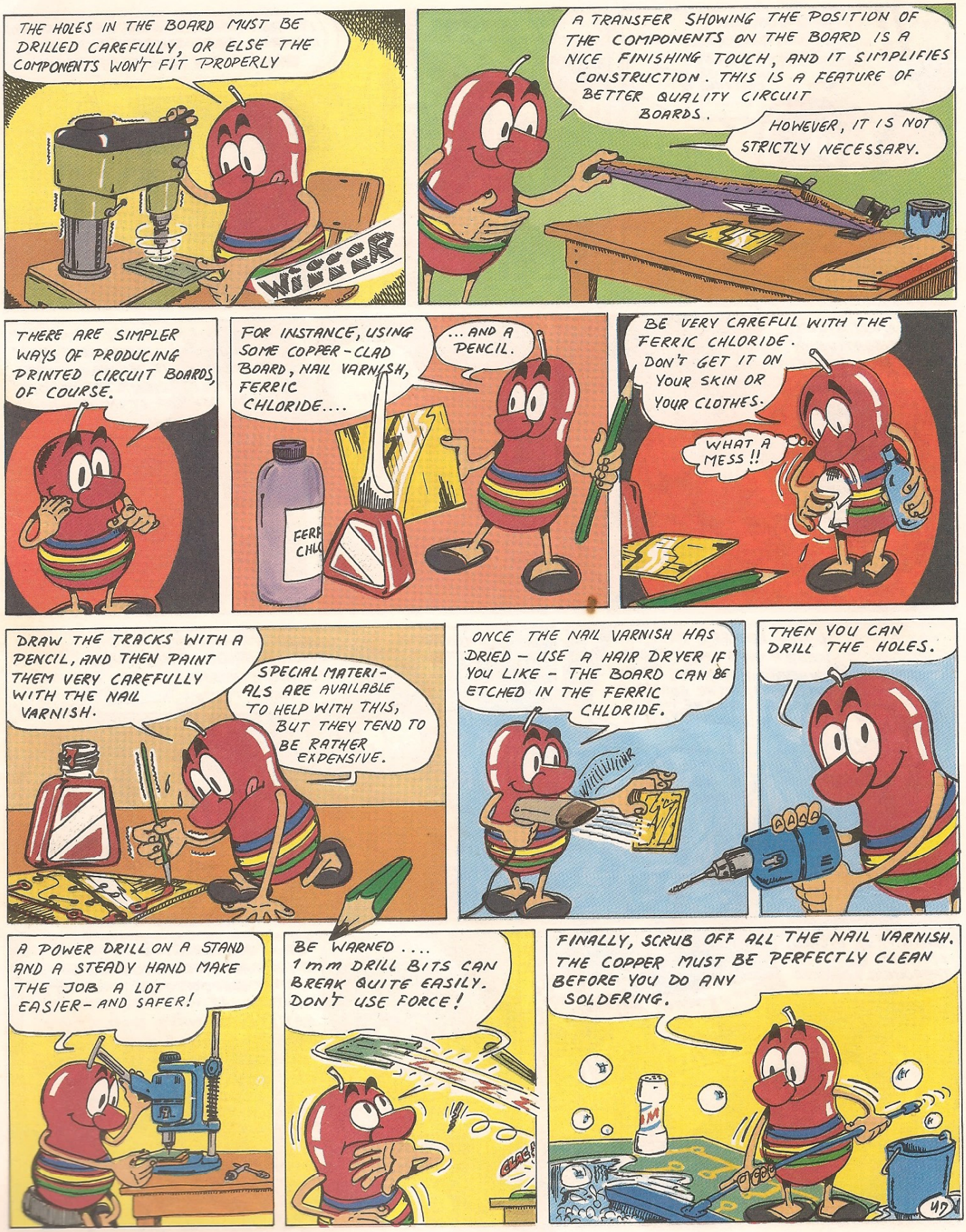

A TYPICAL WORK-BENCH, AT FIRST SIGHT. SOME FASCINATING ELECTRONIC "GADGETS" AND A BOOK. BUT STRANGE THINGS ARE ABOUT TO HAPPEN HERE, AS WE WILL SEE!
THE MYSTERIES OF ELECTRONICS
YD

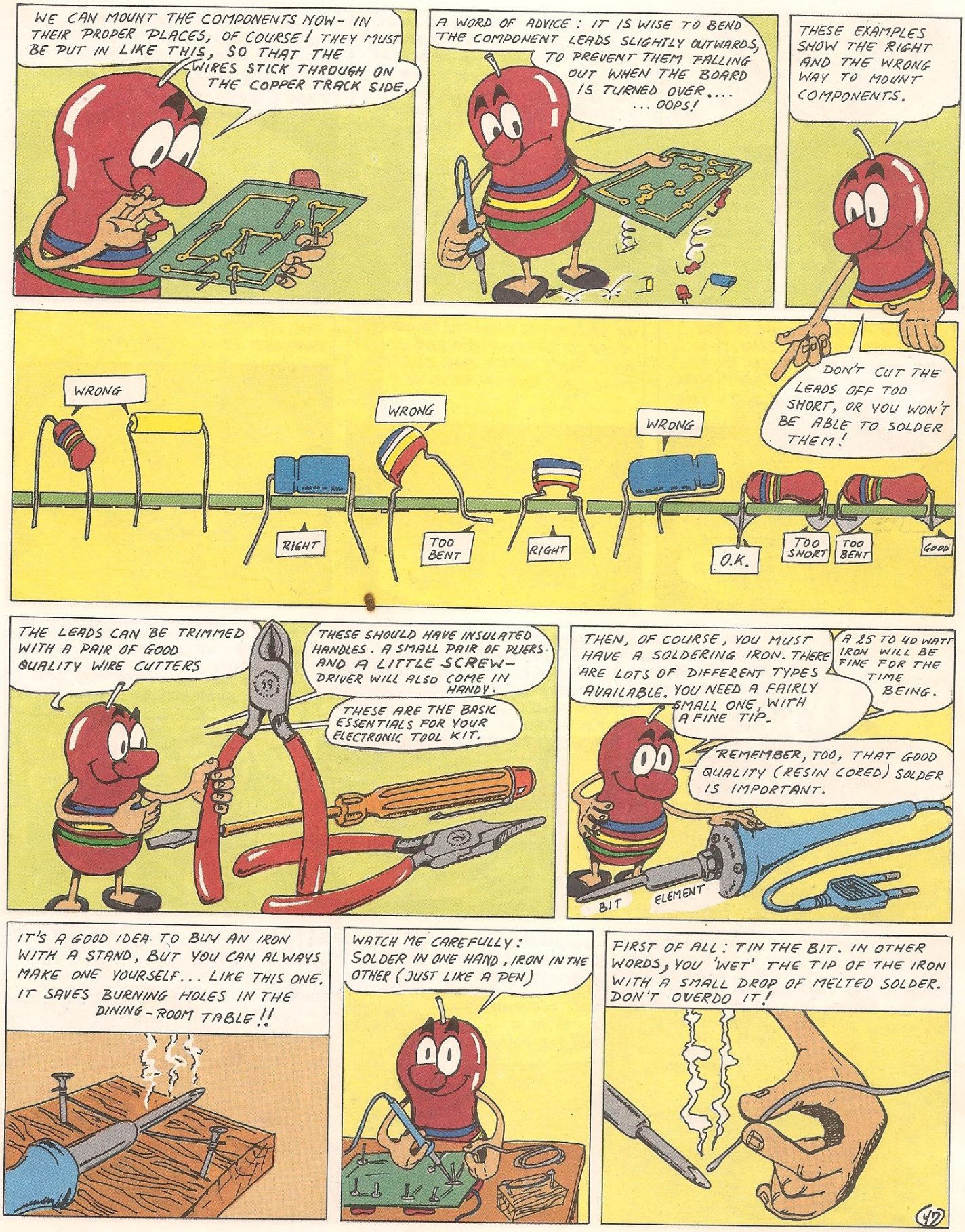

RESI!...
YES, TRANSI?
ARE YOU SURE THAT HE'S GONE?
POSITIVE!
THE MYSTERIES OF ELECTRONICS
GOOD! I WAS DYING TO STRETCH MY LEGS.
I WONDER WHAT THIS IS ABOUT?
YOU CAN FIND OUT SOON ENOUGH, IF YOU CLIMB UP THERE.
HEAVE!
MIND MY DOSE!
GO ON...
JUST A LITTLE BIT MORE...
OOOOF!
THE MYSTERIES OF... OH NO! I DON'T BELIEVE IT!...
HEY, TRANSI! LOOK AT THIS! IT'S A SCREAM!
I'M COMING... BUT YOU MIGHT GIVE ME A HAND!
JUST LOOK AT THIS! THE MYSTERIES OF ELECTRONICS!!!
I DON'T GET IT - WHAT'S SO MYSTERIOUS ABOUT US?
THAT'S WHAT I MEAN! IT'S STUPID!
THERE'S NO "MYSTERY" ABOUT ELECTRONICS. IT'S JUST A GREAT HOBBY!
TRANSI AND I WILL PROVE IT!
WE'LL INTRODUCE YOU TO OUR FRIENDS, THE OTHER COMPONENTS, AND EXPLAIN HOW THEY WORK....
.... AND TEACH YOU A FEW BASIC PRINCIPLES AND SHOW YOU HOW TO SOLDER....
WE'LL SOON CLEAR UP THE "MYSTERIES"!
WE'LL EXPLAIN EVERYTHING STEP BY STEP...
... AND BUILD ALL KINDS OF INTERESTING CIRCUITS!
WELL, WHAT ARE WE WAITING FOR?
4D

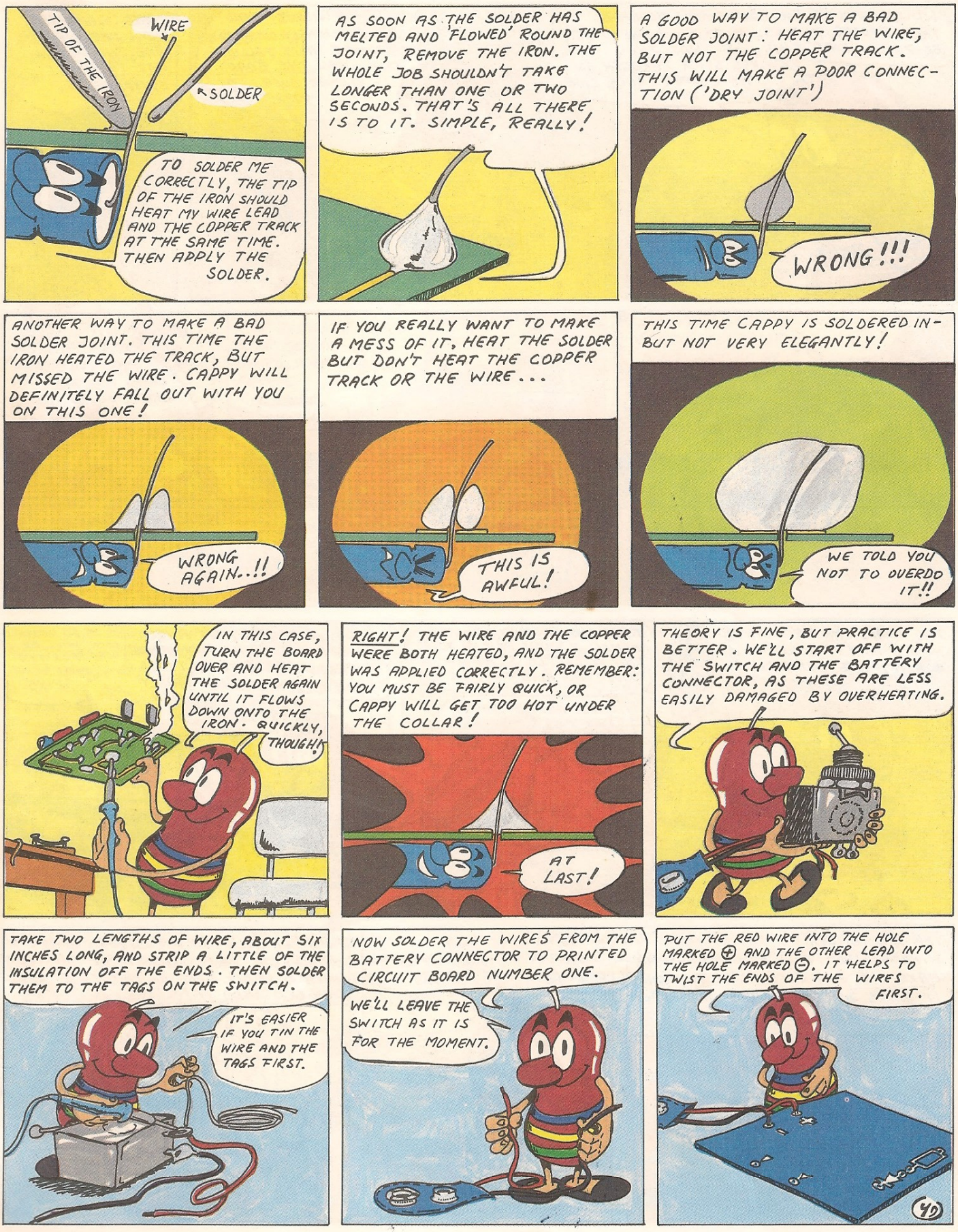

RIGHT! LET'S GO AND LOOK FOR THE OTHERS.
OH DEAR.... DOWN AGAIN....
COME ON!
AAH!
I'LL INTRODUCE YOU TO THE OTHER ELECTRONIC COMPONENTS AND....
PLAFF!
I TRIPPED OVER MY THIRD FOOT!
HERE'S YOUR SHOE.
THE CAPACITOR FAMILY. WE USED TO CALL THEM "CONDENSORS".
SO WHAT....
THIS IS OUR SYMBOL IN CIRCUITS.
IN ALL CIRCUIT DIAGRAMS, WE USE SYMBOLS FOR THE COMPONENTS. IT'S MUCH EASIER AND CLEARER.
DON'T WORRY, THEY'RE VERY EASY TO REMEMBER.
WATCH OUT! WE HAVE A + AND A - END!
DON'T SWAP THEM!
IT HURTS!
THESE ARE ELECTROLYTIC CAPACITORS.
MY SISTERS, THE RESISTORS!
AND HERE'S MY FAMILY: THE SEMICONDUCTORS! WE'RE KNOWN AS THE ACTIVE COMPONENTS, BECAUSE WE MAKE THINGS HAPPEN. WE'RE A VERY LARGE FAMILY, TOO.
INTRODUCE ME FIRST!
HEY, HOLD IT, YOU!
LEDY'S BLUSHING AGAIN!
DIODE
LED
TRANS
YD


AND THERE'S THIS MISCELLANEOUS BUNCH: THE VARIABLE CAPACITORS (1), POTENTIOMETERS (2), LOUDSPEAKERS (3), HEADPHONES (4), AND SO ON.
BLABLABLA... AND BLABLA...
POT.
HE NEVER STOPS!
READING CIRCUIT DIAGRAMS IS QUITE EASY, WHEN YOU KNOW THE TRICKS.
LONG RANGE RADAR MK III A
THE LINES BETWEEN THE SYMBOLS SHOW HOW THE COMPONENTS ARE CONNECTED.
THIS DOT SHOWS THAT THIS IS A CONNECTION...
LIKE THESE PIPES.
NO DOT MEANS NO CONNECTION.
THE COMPONENTS ARE SHOWN AS SYMBOLS, WITH THE VALUE AND COMPONENT NUMBER WRITTEN NEARBY.
R1
220K
C1
47pF
NOWADAYS, COMPONENTS ARE USUALLY MOUNTED ON A PRINTED CIRCUIT BOARD.
NOT SO LONG AGO, YARDS AND YARDS OF COLOURED WIRE WERE USED FOR CONNECTIONS BETWEEN THE COMPONENTS....
OOPS!
SOMETIMES IT WAS QUITE NEAT, BUT MORE OFTEN THAN NOT IT WAS ONE BIG....
MESS!
A PRINTED CIRCUIT BOARD IS A MUCH BETTER SOLUTION. THE COPPER TRACKS REPLACE MOST OF THE WIRING.
SCRAM!
WE PREFER TO BE "SOLDERED" INTO PLACE. PROVIDED YOU USE THE RIGHT TYPE OF SOLDER, THERE IS NO BETTER WAY OF MAKING A CONNECTION!
THIS IS THE STUFF I LIKE.
MULTICORE SOLDER
LET ME SHOW YOU HOW A PRINTED CIRCUIT BOARD IS MADE.
THIS IS ONE WAY OF DOING IT.
45


BASED ON THE CIRCUIT DIAGRAM, I DRAW A TRACK PATTERN ON PAPER. AFTER CHECKING IT....
THE NEXT STEP IS TO TAKE A PHOTO OF IT.
PHOTO LAB
I'M PUTTING MY ORIGINAL DRAWING UNDER A REPRODUCER (THIS IS JUST A BIG CAMERA).
NOW I GET A LIFE-SIZE NEGATIVE OF THE TRACK PATTERN.
I'M DEVELOPING THE NEGATIVE.
WHEN IT'S DRY, I LAY IT ON TOP OF A PIECE OF LIGHT-SENSITIVE PRINTED CIRCUIT BOARD. I USE ULTRA-VIOLET LIGHT TO "EXPOSE" IT, THEN DEVELOP IT IN A SPECIAL CHEMICAL.
THIS LEAVES A PROTECTIVE LAYER OVER THE COPPER, WHERE I WANT THE TRACKS. THE REST OF THE COPPER IS EXPOSED. BY THE WAY, EVEN IN INDUSTRY...
THIS METHOD IS OFTEN USED WHEN ONLY A FEW BOARDS ARE REQUIRED.
THE BOARD CAN NOW BE ETCHED IN A BATH OF FERRIC CHLORIDE. THIS WILL REMOVE ALL THE EXPOSED COPPER, LEAVING THE TRACKS.
I TRY NOT TO SPILL IT, BECAUSE IT LEAVES NASTY STAINS.
FERRIC CHLO-RIDE
WHEN IT IS ETCHED, IT MUST BE THOROUGHLY WASHED AND DRIED.
IT IS VERY WISE TO USE TISSUES - NOT TOWELS!
IT IS INTERESTING TO KNOW THAT THIS TECHNIQUE WAS KNOWN BEFORE THE TWELFTH CENTURY. IT WAS USED BY ARTISTS, TO MAKE WHAT THEY CALL "ETCHINGS". THEY DIDN'T MOUNT ELECTRONIC COMPONENTS ON THEM, THOUGH! MAYBE THEY WOULD HAVE DONE, IF THEY'D KNOWN HOW PRETTY THESE COMPONENTS ARE!
AY, 'TIS SO!
BUT LET'S GET BACK TO OUR JOB.
49


THE HOLES IN THE BOARD MUST BE DRILLED CAREFULLY, OR ELSE THE COMPONENTS WON'T FIT PROPERLY
WIZZZ
A TRANSFER SHOWING THE POSITION OF THE COMPONENTS ON THE BOARD IS A NICE FINISHING TOUCH, AND IT SIMPLIFIES CONSTRUCTION. THIS IS A FEATURE OF BETTER QUALITY CIRCUIT BOARDS.
HOWEVER, IT IS NOT STRICTLY NECESSARY.
THERE ARE SIMPLER WAYS OF PRODUCING PRINTED CIRCUIT BOARDS, OF COURSE.
FOR INSTANCE, USING SOME COPPER-CLAD BOARD, NAIL VARNISH, FERRIC CHLORIDE....
... AND A PENCIL.
FERR CHLO
BE VERY CAREFUL WITH THE FERRIC CHLORIDE. DON'T GET IT ON YOUR SKIN OR YOUR CLOTHES.
WHAT A MESS !!
DRAW THE TRACKS WITH A PENCIL, AND THEN PAINT THEM VERY CAREFULLY WITH THE NAIL VARNISH.
SPECIAL MATERIALS ARE AVAILABLE TO HELP WITH THIS, BUT THEY TEND TO BE RATHER EXPENSIVE.
ONCE THE NAIL VARNISH HAS DRIED - USE A HAIR DRYER IF YOU LIKE - THE BOARD CAN BE ETCHED IN THE FERRIC CHLORIDE.
THEN YOU CAN DRILL THE HOLES.
A POWER DRILL ON A STAND AND A STEADY HAND MAKE THE JOB A LOT EASIER - AND SAFER!
BE WARNED .... 1mm DRILL BITS CAN BREAK QUITE EASILY. DON'T USE FORCE!
CLACK
FINALLY, SCRUB OFF ALL THE NAIL VARNISH. THE COPPER MUST BE PERFECTLY CLEAN BEFORE YOU DO ANY SOLDERING.
UD


WE CAN MOUNT THE COMPONENTS NOW - IN THEIR PROPER PLACES, OF COURSE! THEY MUST BE PUT IN LIKE THIS, SO THAT THE WIRES STICK THROUGH ON THE COPPER TRACK SIDE.
A WORD OF ADVICE: IT IS WISE TO BEND THE COMPONENT LEADS SLIGHTLY OUTWARDS, TO PREVENT THEM FALLING OUT WHEN THE BOARD IS TURNED OVER.... ... OOPS!
THESE EXAMPLES SHOW THE RIGHT AND THE WRONG WAY TO MOUNT COMPONENTS.
DON'T CUT THE LEADS OFF TOO SHORT, OR YOU WON'T BE ABLE TO SOLDER THEM!
WRONG
RIGHT
WRONG
TOO BENT
RIGHT
WRONG
O.K.
TOO SHORT
TOO BENT
GOOD
THE LEADS CAN BE TRIMMED WITH A PAIR OF GOOD QUALITY WIRE CUTTERS
THESE SHOULD HAVE INSULATED HANDLES. A SMALL PAIR OF PLIERS AND A LITTLE SCREW-DRIVER WILL ALSO COME IN HANDY.
THESE ARE THE BASIC ESSENTIALS FOR YOUR ELECTRONIC TOOL KIT.
THEN, OF COURSE, YOU MUST HAVE A SOLDERING IRON. THERE ARE LOTS OF DIFFERENT TYPES AVAILABLE. YOU NEED A FAIRLY SMALL ONE, WITH A FINE TIP.
A 25 TO 40 WATT IRON WILL BE FINE FOR THE TIME BEING.
REMEMBER, TOO, THAT GOOD QUALITY (RESIN CORED) SOLDER IS IMPORTANT.
BIT
ELEMENT
IT'S A GOOD IDEA TO BUY AN IRON WITH A STAND, BUT YOU CAN ALWAYS MAKE ONE YOURSELF... LIKE THIS ONE. IT SAVES BURNING HOLES IN THE DINING-ROOM TABLE!!
WATCH ME CAREFULLY: SOLDER IN ONE HAND, IRON IN THE OTHER (JUST LIKE A PEN)
FIRST OF ALL: TIN THE BIT. IN OTHER WORDS, YOU 'WET' THE TIP OF THE IRON WITH A SMALL DROP OF MELTED SOLDER. DON'T OVERDO IT!
4D


TIP OF THE IRON
WIRE
SOLDER
TO SOLDER ME CORRECTLY, THE TIP OF THE IRON SHOULD HEAT MY WIRE LEAD AND THE COPPER TRACK AT THE SAME TIME. THEN APPLY THE SOLDER.
AS SOON AS THE SOLDER HAS MELTED AND 'FLOWED' ROUND THE JOINT, REMOVE THE IRON. THE WHOLE JOB SHOULDN'T TAKE LONGER THAN ONE OR TWO SECONDS. THAT'S ALL THERE IS TO IT. SIMPLE, REALLY!
A GOOD WAY TO MAKE A BAD SOLDER JOINT: HEAT THE WIRE, BUT NOT THE COPPER TRACK. THIS WILL MAKE A POOR CONNECTION ('DRY JOINT')
WRONG!!!
ANOTHER WAY TO MAKE A BAD SOLDER JOINT. THIS TIME THE IRON HEATED THE TRACK, BUT MISSED THE WIRE. CAPPY WILL DEFINITELY FALL OUT WITH YOU ON THIS ONE!
WRONG AGAIN..!!
IF YOU REALLY WANT TO MAKE A MESS OF IT, HEAT THE SOLDER BUT DON'T HEAT THE COPPER TRACK OR THE WIRE...
THIS IS AWFUL!
THIS TIME CAPPY IS SOLDERED IN- BUT NOT VERY ELEGANTLY!
WE TOLD YOU NOT TO OVERDO IT!!
IN THIS CASE, TURN THE BOARD OVER AND HEAT THE SOLDER AGAIN UNTIL IT FLOWS DOWN ONTO THE IRON. QUICKLY, THOUGH!
RIGHT! THE WIRE AND THE COPPER WERE BOTH HEATED, AND THE SOLDER WAS APPLIED CORRECTLY. REMEMBER: YOU MUST BE FAIRLY QUICK, OR CAPPY WILL GET TOO HOT UNDER THE COLLAR!
AT LAST!
THEORY IS FINE, BUT PRACTICE IS BETTER. WE'LL START OFF WITH THE SWITCH AND THE BATTERY CONNECTOR, AS THESE ARE LESS EASILY DAMAGED BY OVERHEATING.
TAKE TWO LENGTHS OF WIRE, ABOUT SIX INCHES LONG, AND STRIP A LITTLE OF THE INSULATION OFF THE ENDS. THEN SOLDER THEM TO THE TAGS ON THE SWITCH.
IT'S EASIER IF YOU TIN THE WIRE AND THE TAGS FIRST.
NOW SOLDER THE WIRES FROM THE BATTERY CONNECTOR TO PRINTED CIRCUIT BOARD NUMBER ONE.
WE'LL LEAVE THE SWITCH AS IT IS FOR THE MOMENT.
PUT THE RED WIRE INTO THE HOLE MARKED ⊕ AND THE OTHER LEAD INTO THE HOLE MARKED ⊖. IT HELPS TO TWIST THE ENDS OF THE WIRES FIRST.
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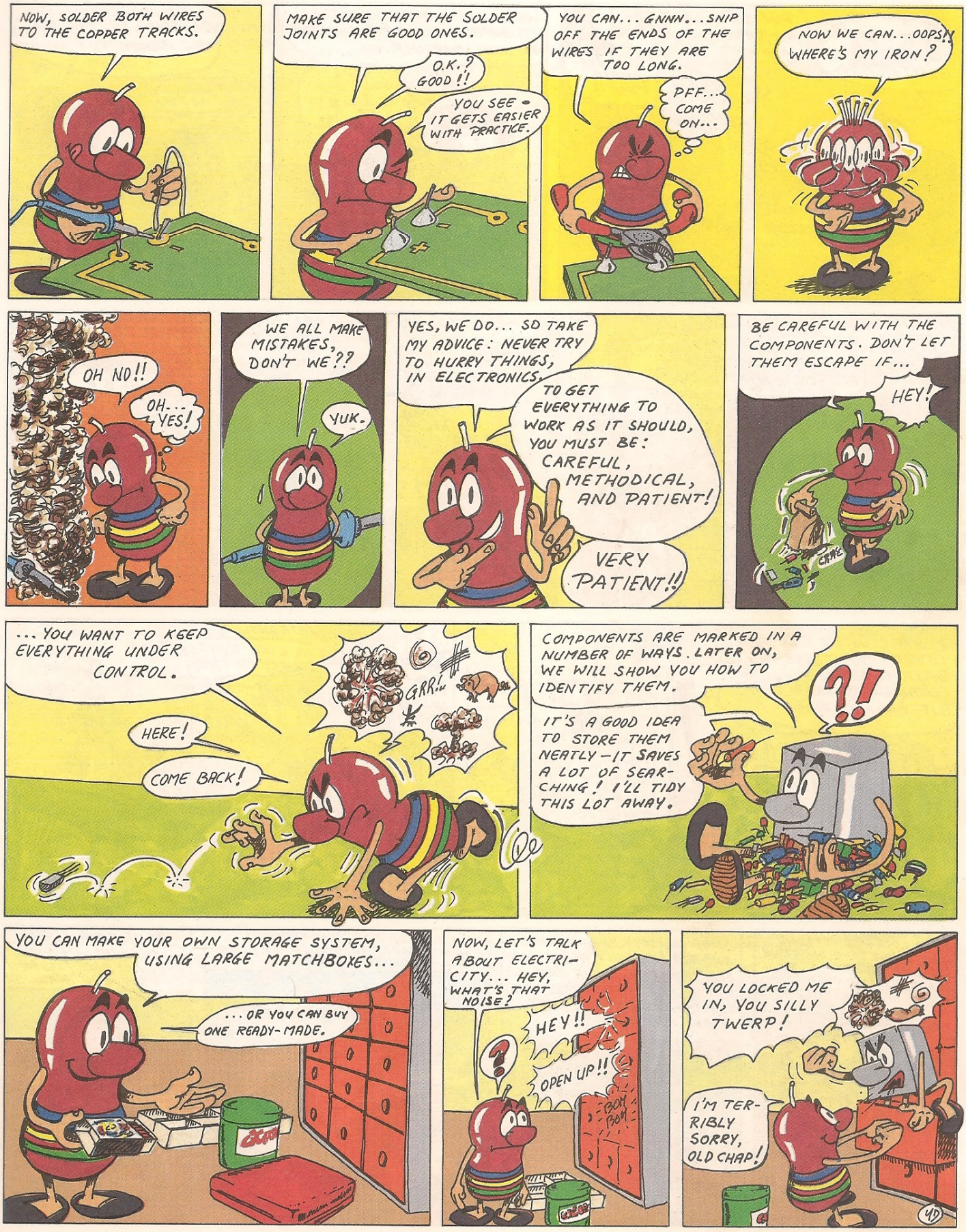
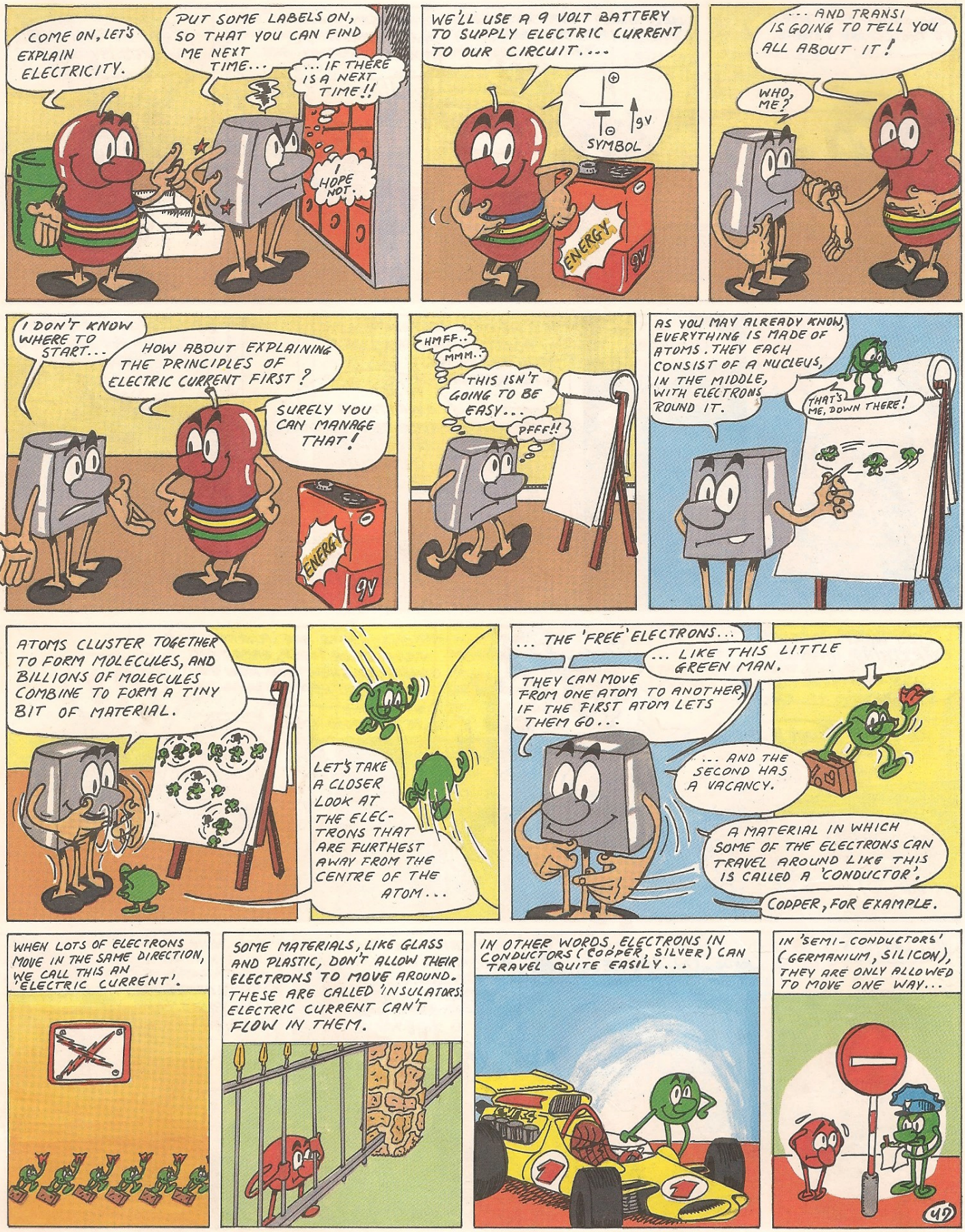
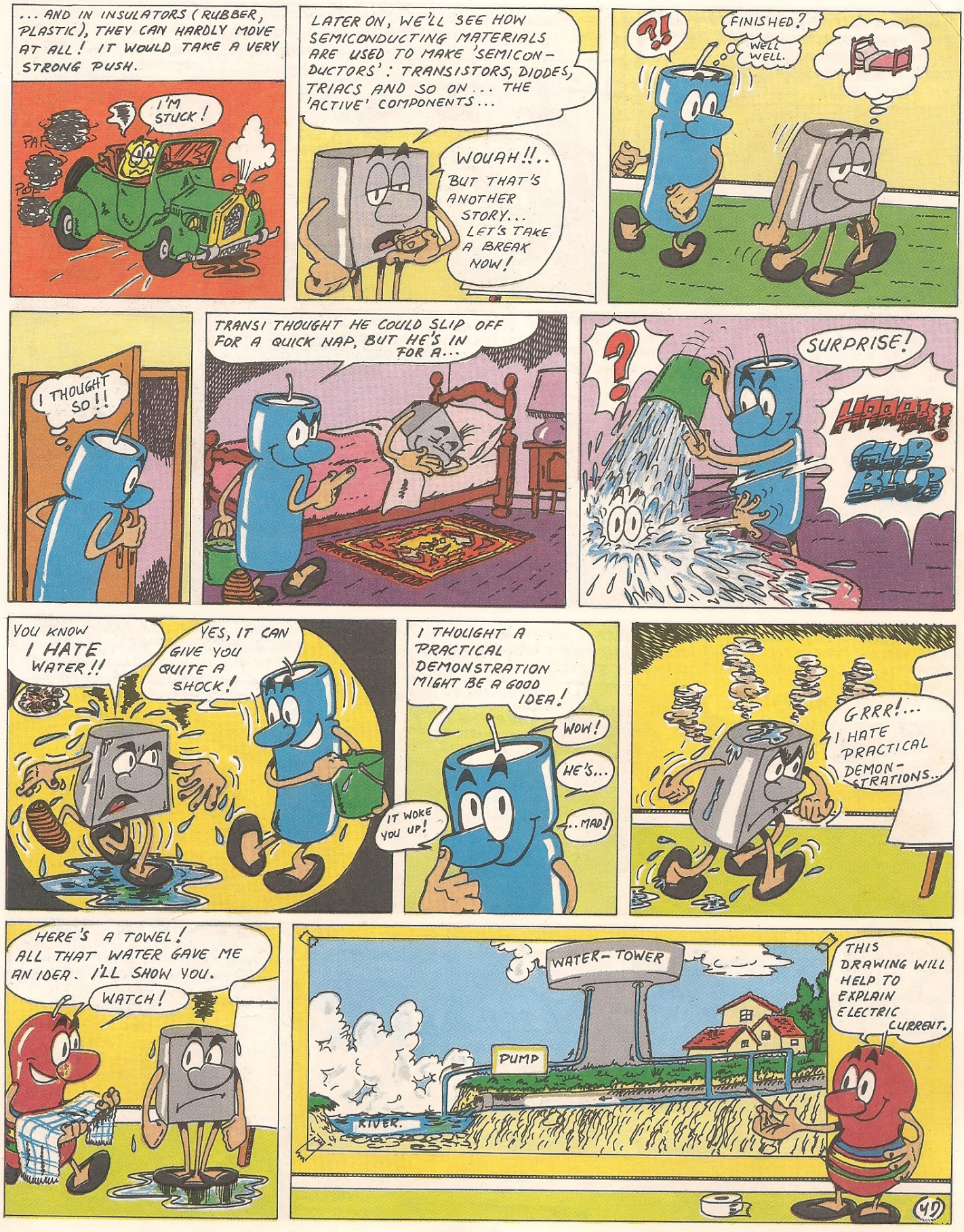
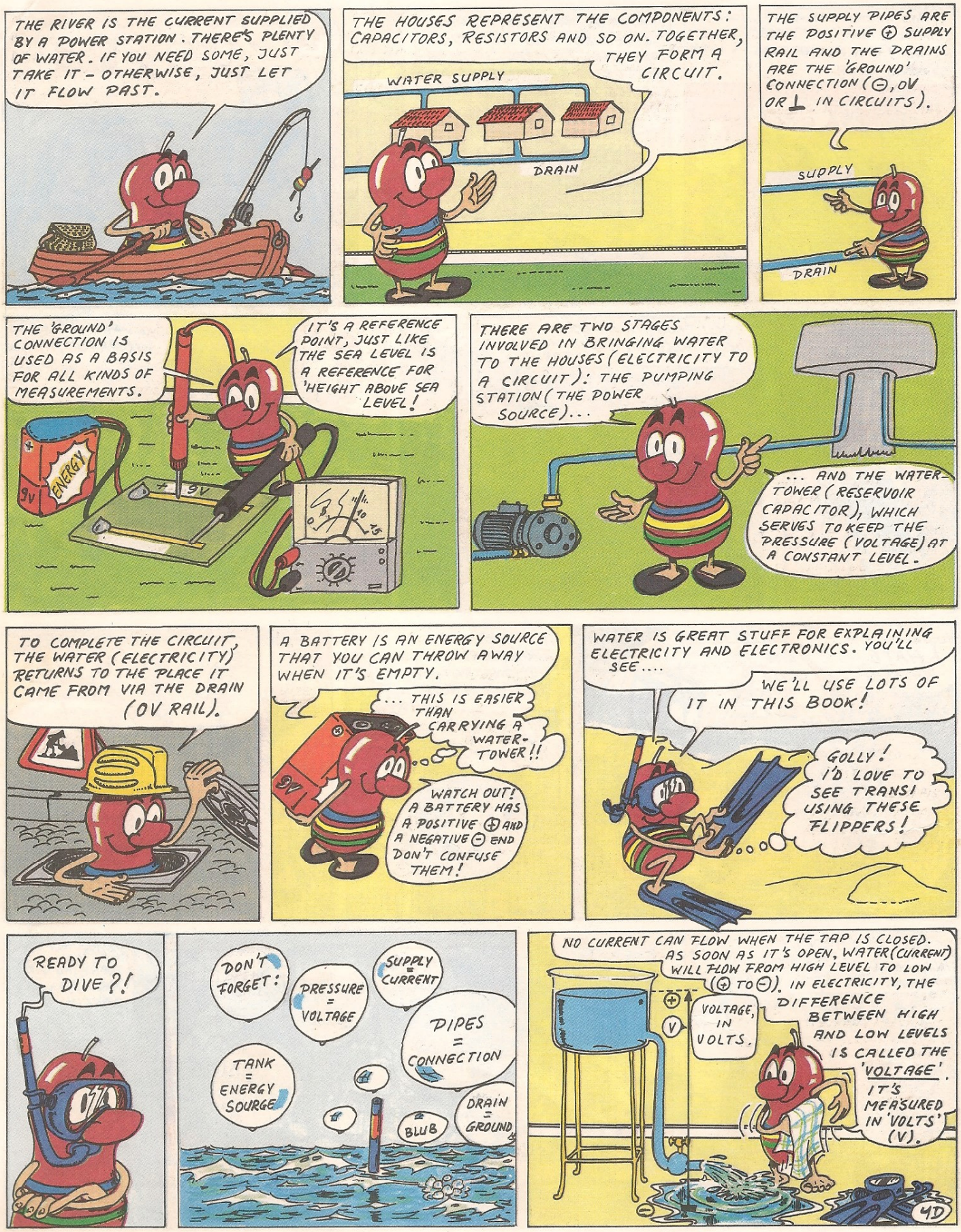
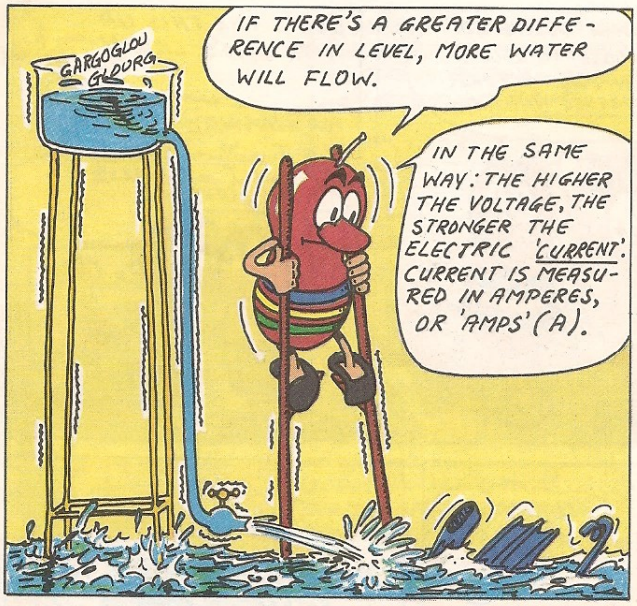
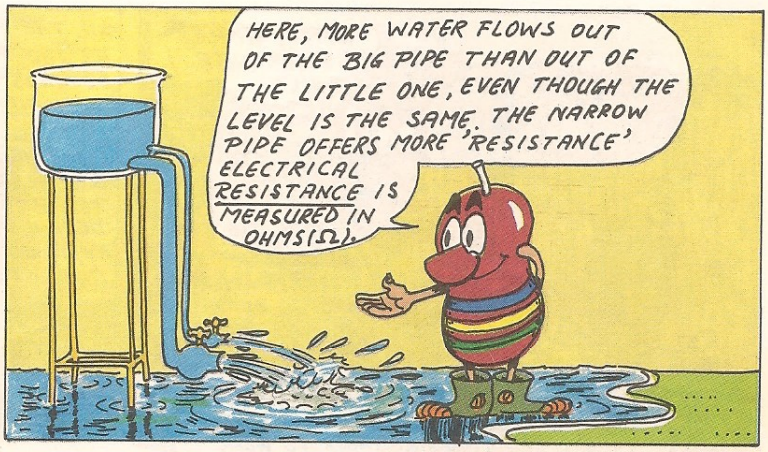

NOW, SOLDER BOTH WIRES TO THE COPPER TRACKS.
MAKE SURE THAT THE SOLDER JOINTS ARE GOOD ONES.
O.K.? GOOD!!
YOU SEE - IT GETS EASIER WITH PRACTICE.
YOU CAN... GNNN... SNIP OFF THE ENDS OF THE WIRES IF THEY ARE TOO LONG.
PFF... COME ON...
NOW WE CAN... OOPS!! WHERE'S MY IRON?
OH NO!!
OH... YES!
WE ALL MAKE MISTAKES, DON'T WE??
YUK.
YES, WE DO... SO TAKE MY ADVICE: NEVER TRY TO HURRY THINGS, IN ELECTRONICS.
TO GET EVERYTHING TO WORK AS IT SHOULD, YOU MUST BE: CAREFUL, METHODICAL, AND PATIENT!
VERY PATIENT!!
BE CAREFUL WITH THE COMPONENTS. DON'T LET THEM ESCAPE IF...
HEY!
CRUNCH
...YOU WANT TO KEEP EVERYTHING UNDER CONTROL.
GRRR!...
HERE!
COME BACK!
COMPONENTS ARE MARKED IN A NUMBER OF WAYS. LATER ON, WE WILL SHOW YOU HOW TO IDENTIFY THEM.
?!
IT'S A GOOD IDEA TO STORE THEM NEATLY - IT SAVES A LOT OF SEARCHING! I'LL TIDY THIS LOT AWAY.
YOU CAN MAKE YOUR OWN STORAGE SYSTEM, USING LARGE MATCHBOXES...
...OR YOU CAN BUY ONE READY-MADE.
NOW, LET'S TALK ABOUT ELECTRICITY... HEY, WHAT'S THAT NOISE?
?
HEY!!
OPEN UP!!
BOM BOM
YOU LOCKED ME IN, YOU SILLY TWERP!
I'M TERRIBLY SORRY, OLD CHAP!
MD

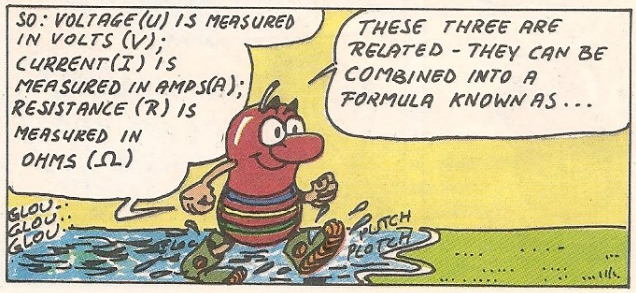

COME ON, LET'S EXPLAIN ELECTRICITY.
PUT SOME LABELS ON, SO THAT YOU CAN FIND ME NEXT TIME...
... IF THERE IS A NEXT TIME!!
I HOPE NOT.
WE'LL USE A 9 VOLT BATTERY TO SUPPLY ELECTRIC CURRENT TO OUR CIRCUIT....
9V
SYMBOL
ENERGY
9V
... AND TRANSI IS GOING TO TELL YOU ALL ABOUT IT!
WHO, ME?
I DON'T KNOW WHERE TO START...
HOW ABOUT EXPLAINING THE PRINCIPLES OF ELECTRIC CURRENT FIRST?
SURELY YOU CAN MANAGE THAT!
ENERGY
9V
HMFF..
MMM..
THIS ISN'T GOING TO BE EASY...
PFFF!!
AS YOU MAY ALREADY KNOW, EVERYTHING IS MADE OF ATOMS. THEY EACH CONSIST OF A NUCLEUS, IN THE MIDDLE, WITH ELECTRONS ROUND IT.
THAT'S ME, DOWN THERE!
ATOMS CLUSTER TOGETHER TO FORM MOLECULES, AND BILLIONS OF MOLECULES COMBINE TO FORM A TINY BIT OF MATERIAL.
LET'S TAKE A CLOSER LOOK AT THE ELECTRONS THAT ARE FURTHEST AWAY FROM THE CENTRE OF THE ATOM...
... THE 'FREE' ELECTRONS...
... LIKE THIS LITTLE GREEN MAN.
THEY CAN MOVE FROM ONE ATOM TO ANOTHER, IF THE FIRST ATOM LETS THEM GO...
... AND THE SECOND HAS A VACANCY.
A MATERIAL IN WHICH SOME OF THE ELECTRONS CAN TRAVEL AROUND LIKE THIS IS CALLED A 'CONDUCTOR'.
COPPER, FOR EXAMPLE.
WHEN LOTS OF ELECTRONS MOVE IN THE SAME DIRECTION, WE CALL THIS AN 'ELECTRIC CURRENT'.
SOME MATERIALS, LIKE GLASS AND PLASTIC, DON'T ALLOW THEIR ELECTRONS TO MOVE AROUND. THESE ARE CALLED 'INSULATORS'. ELECTRIC CURRENT CAN'T FLOW IN THEM.
IN OTHER WORDS, ELECTRONS IN CONDUCTORS (COPPER, SILVER) CAN TRAVEL QUITE EASILY...
IN 'SEMI-CONDUCTORS' (GERMANIUM, SILICON), THEY ARE ONLY ALLOWED TO MOVE ONE WAY...

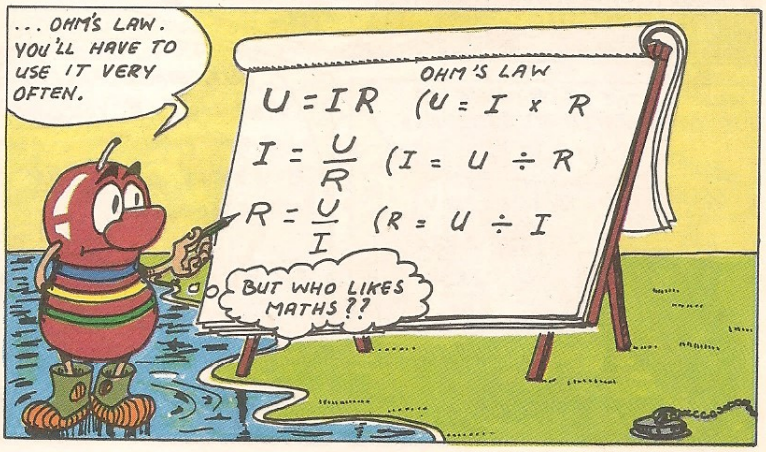

... AND IN INSULATORS (RUBBER, PLASTIC), THEY CAN HARDLY MOVE AT ALL! IT WOULD TAKE A VERY STRONG PUSH.
I'M STUCK!
PAF
POF
LATER ON, WE'LL SEE HOW SEMICONDUCTING MATERIALS ARE USED TO MAKE 'SEMICONDUCTORS': TRANSISTORS, DIODES, TRIACS AND SO ON... THE 'ACTIVE' COMPONENTS...
WOUAH!!.. BUT THAT'S ANOTHER STORY... LET'S TAKE A BREAK NOW!
?!
FINISHED?
WELL WELL.
I THOUGHT SO!!
TRANSI THOUGHT HE COULD SLIP OFF FOR A QUICK NAP, BUT HE'S IN FOR A...
?
SURPRISE!
GLUB GLUB
YOU KNOW I HATE WATER!!
YES, IT CAN GIVE YOU QUITE A SHOCK!
I THOUGHT A PRACTICAL DEMONSTRATION MIGHT BE A GOOD IDEA!
WOW!
HE'S...
..MAD!
IT WOKE YOU UP!
GRRR!... I HATE PRACTICAL DEMONSTRATIONS...
HERE'S A TOWEL! ALL THAT WATER GAVE ME AN IDEA. I'LL SHOW YOU.
WATCH!
WATER-TOWER
PUMP
RIVER.
THIS DRAWING WILL HELP TO EXPLAIN ELECTRIC CURRENT.
49

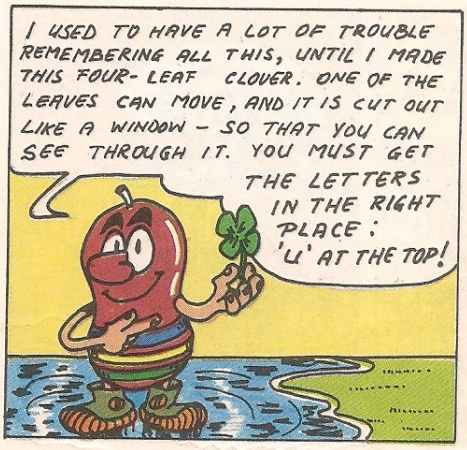

THE RIVER IS THE CURRENT SUPPLIED BY A POWER STATION. THERE'S PLENTY OF WATER. IF YOU NEED SOME, JUST TAKE IT - OTHERWISE, JUST LET IT FLOW PAST.
THE HOUSES REPRESENT THE COMPONENTS: CAPACITORS, RESISTORS AND SO ON. TOGETHER, THEY FORM A CIRCUIT.
WATER SUPPLY
DRAIN
THE SUPPLY PIPES ARE THE POSITIVE ⊕ SUPPLY RAIL AND THE DRAINS ARE THE 'GROUND' CONNECTION (⊖, 0V OR ⊥ IN CIRCUITS).
SUPPLY
DRAIN
THE 'GROUND' CONNECTION IS USED AS A BASIS FOR ALL KINDS OF MEASUREMENTS.
IT'S A REFERENCE POINT, JUST LIKE THE SEA LEVEL IS A REFERENCE FOR 'HEIGHT ABOVE SEA LEVEL!
ENERGY
9V
THERE ARE TWO STAGES INVOLVED IN BRINGING WATER TO THE HOUSES (ELECTRICITY TO A CIRCUIT): THE PUMPING STATION (THE POWER SOURCE)...
... AND THE WATER-TOWER (RESERVOIR CAPACITOR), WHICH SERVES TO KEEP THE PRESSURE (VOLTAGE) AT A CONSTANT LEVEL.
TO COMPLETE THE CIRCUIT, THE WATER (ELECTRICITY) RETURNS TO THE PLACE IT CAME FROM VIA THE DRAIN (0V RAIL).
A BATTERY IS AN ENERGY SOURCE THAT YOU CAN THROW AWAY WHEN IT'S EMPTY.
... THIS IS EASIER THAN CARRYING A WATER-TOWER!!
WATCH OUT! A BATTERY HAS A POSITIVE ⊕ AND A NEGATIVE ⊖ END DON'T CONFUSE THEM!
9V
WATER IS GREAT STUFF FOR EXPLAINING ELECTRICITY AND ELECTRONICS. YOU'LL SEE....
WE'LL USE LOTS OF IT IN THIS BOOK!
GOLLY! I'D LOVE TO SEE TRANS! USING THESE FLIPPERS!
READY TO DIVE?!
DON'T FORGET:
PRESSURE = VOLTAGE
SUPPLY = CURRENT
PIPES = CONNECTION
TANK = ENERGY SOURCE
BULB
DRAIN = GROUND
NO CURRENT CAN FLOW WHEN THE TAP IS CLOSED. AS SOON AS IT'S OPEN, WATER (CURRENT) WILL FLOW FROM HIGH LEVEL TO LOW (⊕ TO ⊖). IN ELECTRICITY, THE DIFFERENCE BETWEEN HIGH AND LOW LEVELS IS CALLED THE 'VOLTAGE'. IT'S MEASURED IN 'VOLTS' (V).
VOLTAGE, IN VOLTS.
V
4D

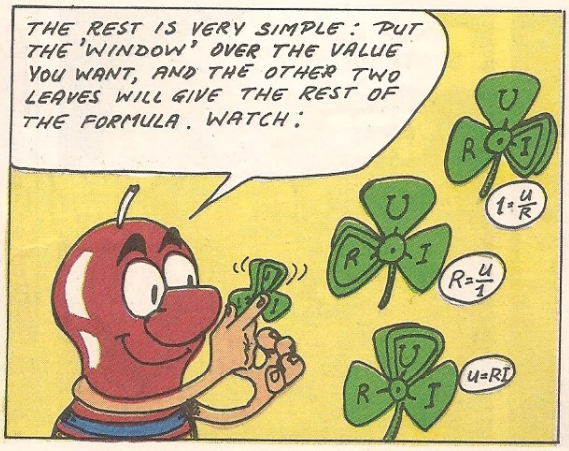

GARGOGLOU GLOURG
IF THERE'S A GREATER DIFFERENCE IN LEVEL, MORE WATER WILL FLOW.
IN THE SAME WAY: THE HIGHER THE VOLTAGE, THE STRONGER THE ELECTRIC 'CURRENT'. CURRENT IS MEASURED IN AMPERES, OR 'AMPS' (A).


HERE, MORE WATER FLOWS OUT OF THE BIG PIPE THAN OUT OF THE LITTLE ONE, EVEN THOUGH THE LEVEL IS THE SAME. THE NARROW PIPE OFFERS MORE 'RESISTANCE' ELECTRICAL RESISTANCE IS MEASURED IN OHMS (Ω).

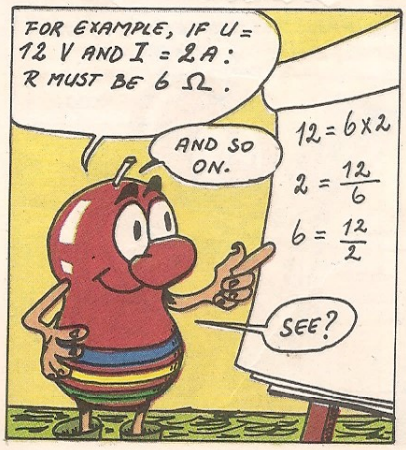

SO: VOLTAGE (U) IS MEASURED IN VOLTS (V); CURRENT (I) IS MEASURED IN AMPS (A); RESISTANCE (R) IS MEASURED IN OHMS (Ω)
THESE THREE ARE RELATED - THEY CAN BE COMBINED INTO A FORMULA KNOWN AS...
GLOU GLOU GLOU...
GLOU
PLOTCH PLOTCH

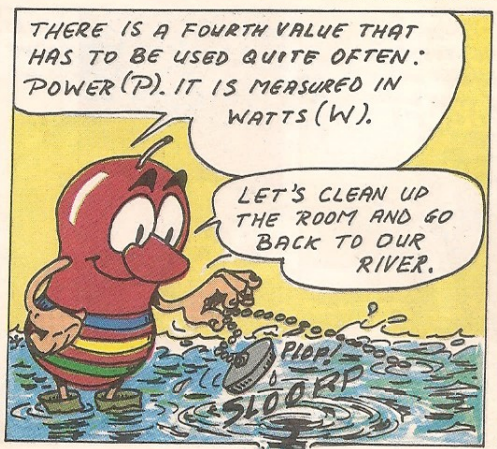

... OHM'S LAW. YOU'LL HAVE TO USE IT VERY OFTEN.
OHM'S LAW
U = I R (U = I × R
I = U/R (I = U ÷ R
R = U/I (R = U ÷ I
BUT WHO LIKES MATHS??

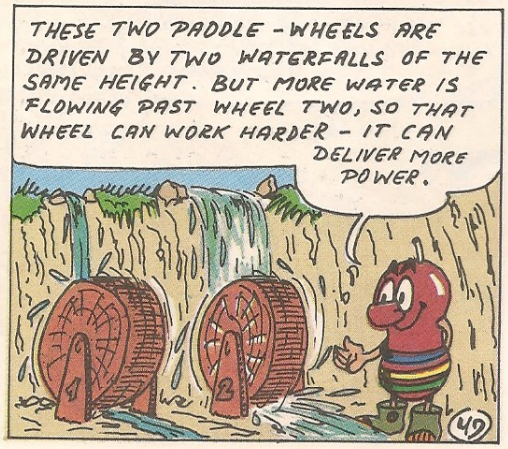

I USED TO HAVE A LOT OF TROUBLE REMEMBERING ALL THIS, UNTIL I MADE THIS FOUR-LEAF CLOVER. ONE OF THE LEAVES CAN MOVE, AND IT IS CUT OUT LIKE A WINDOW - SO THAT YOU CAN SEE THROUGH IT. YOU MUST GET THE LETTERS IN THE RIGHT PLACE: 'U' AT THE TOP!

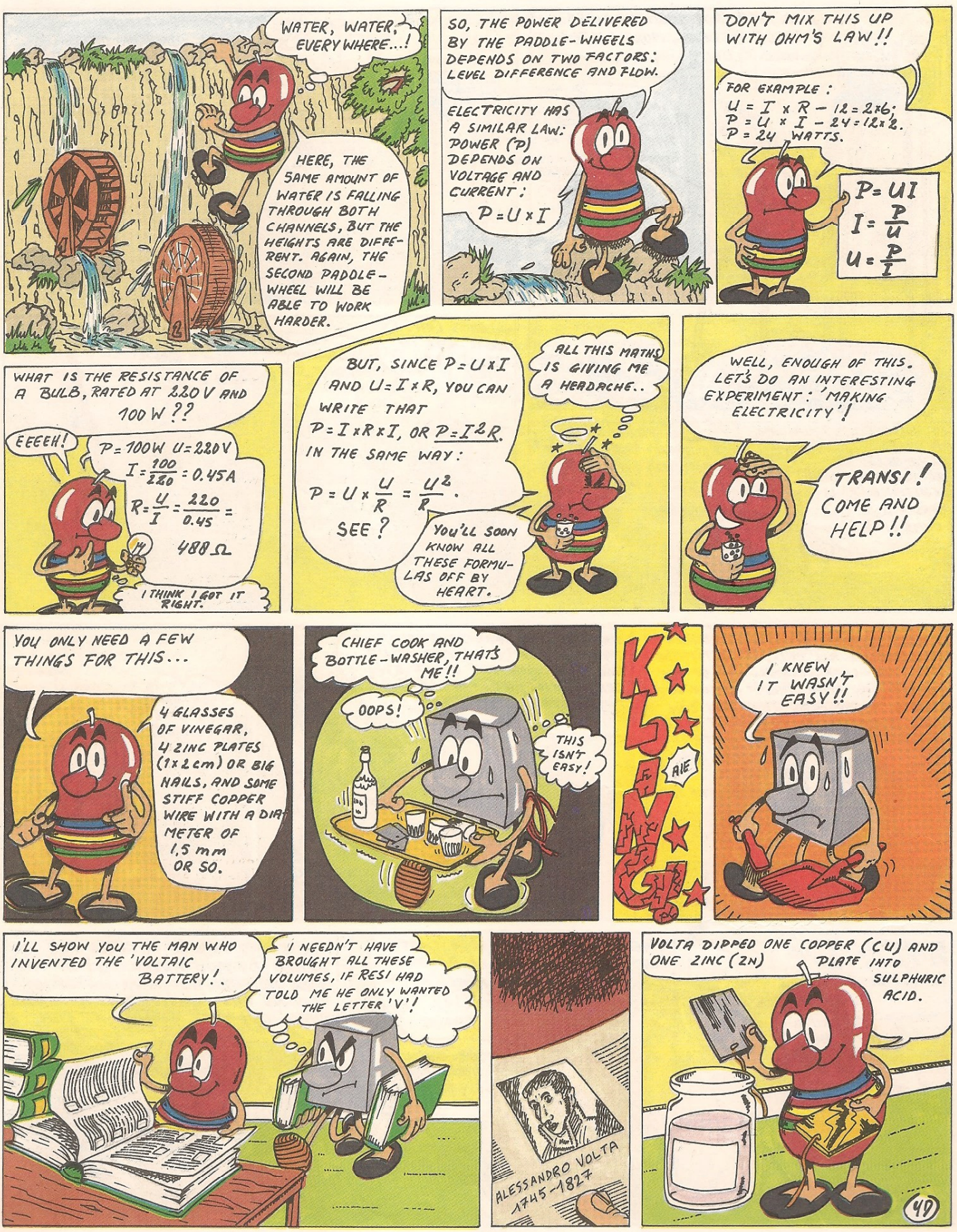

THE REST IS VERY SIMPLE: PUT THE 'WINDOW' OVER THE VALUE YOU WANT, AND THE OTHER TWO LEAVES WILL GIVE THE REST OF THE FORMULA. WATCH:
U
R I
I = U/R
R = U/I
U = RI

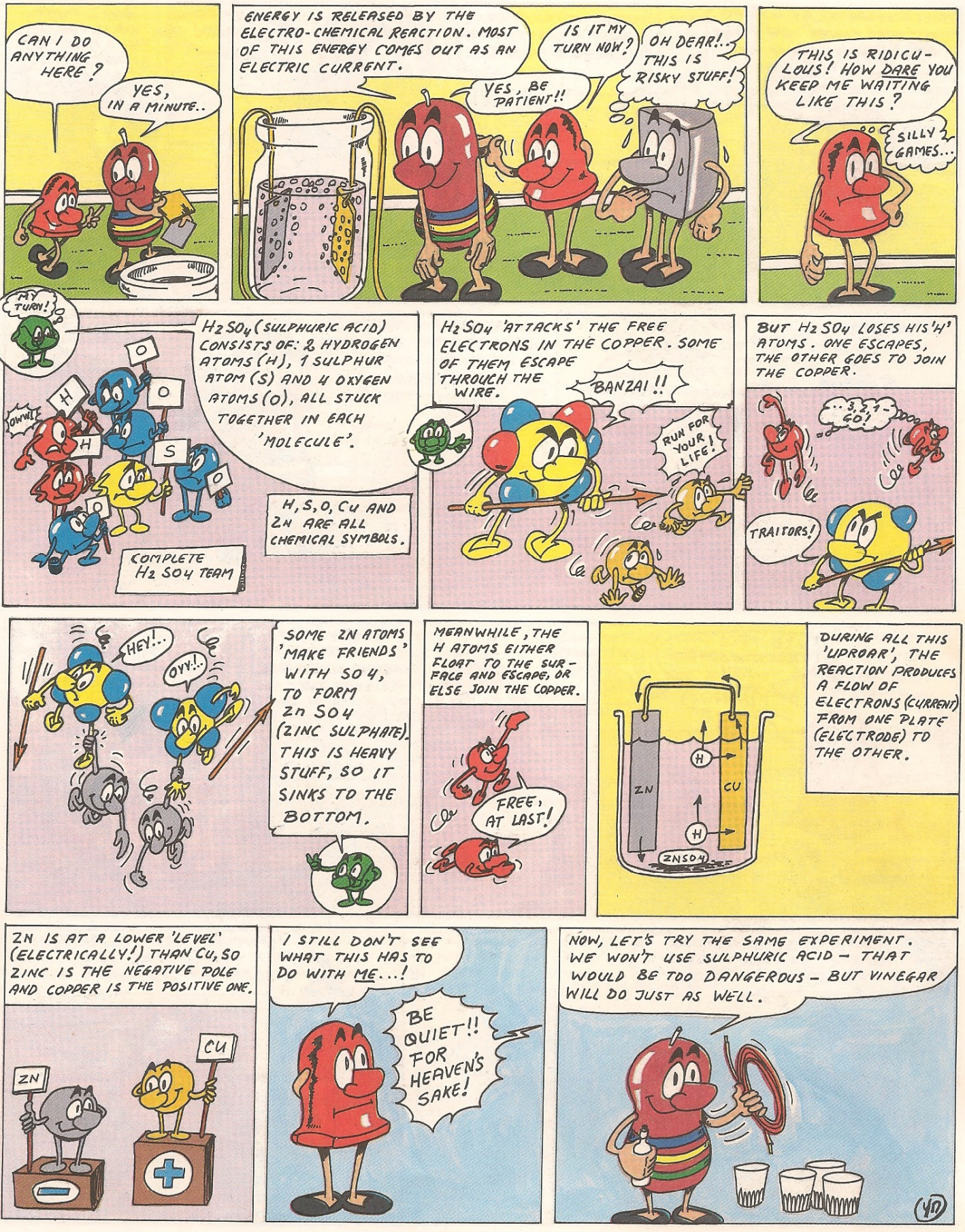

GOOD LORD! IT'S STILL RISING!!

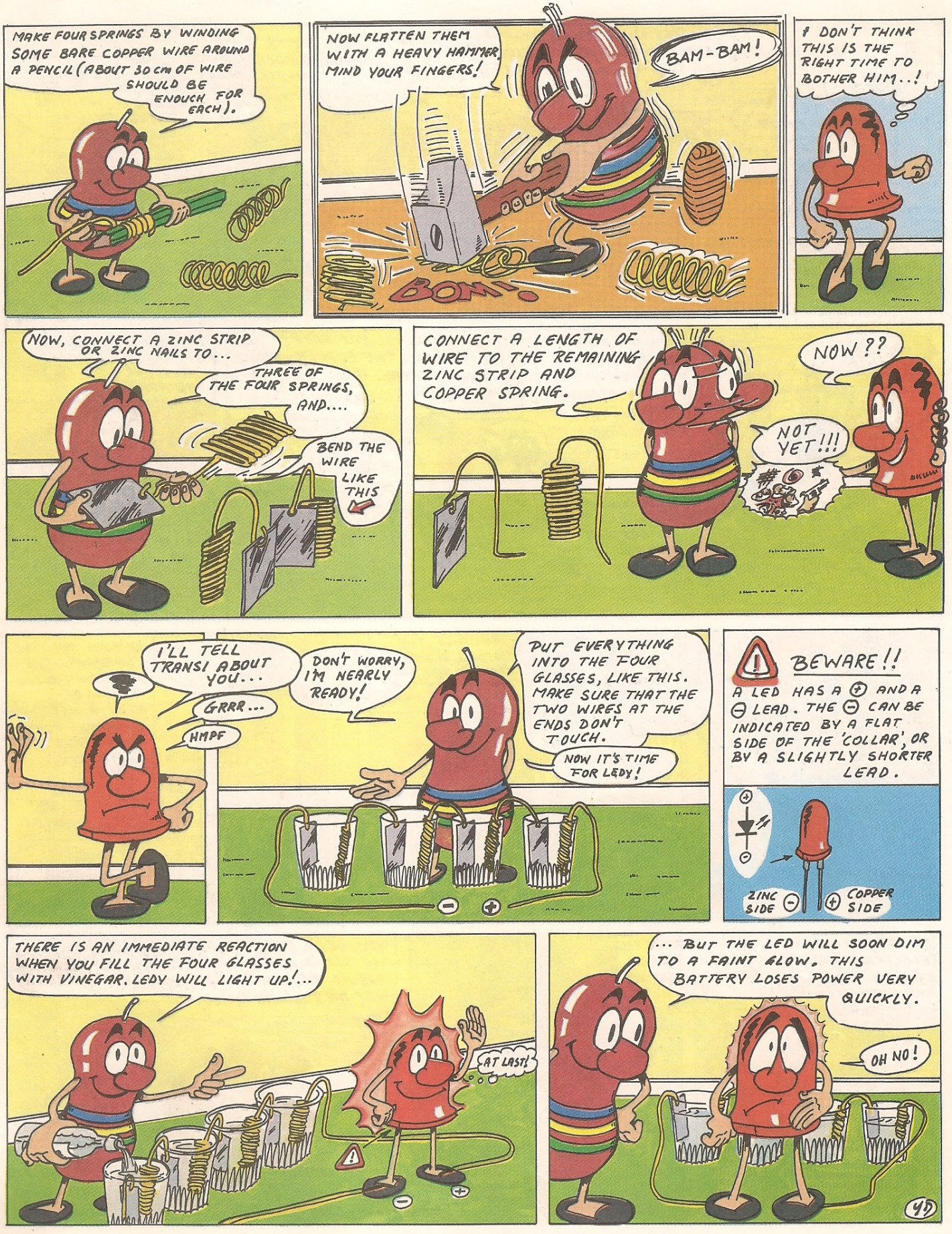

FOR EXAMPLE, IF U = 12 V AND I = 2 A: R MUST BE 6 Ω.
AND SO ON.
12 = 6 × 2
2 = 12/6
6 = 12/2
SEE?

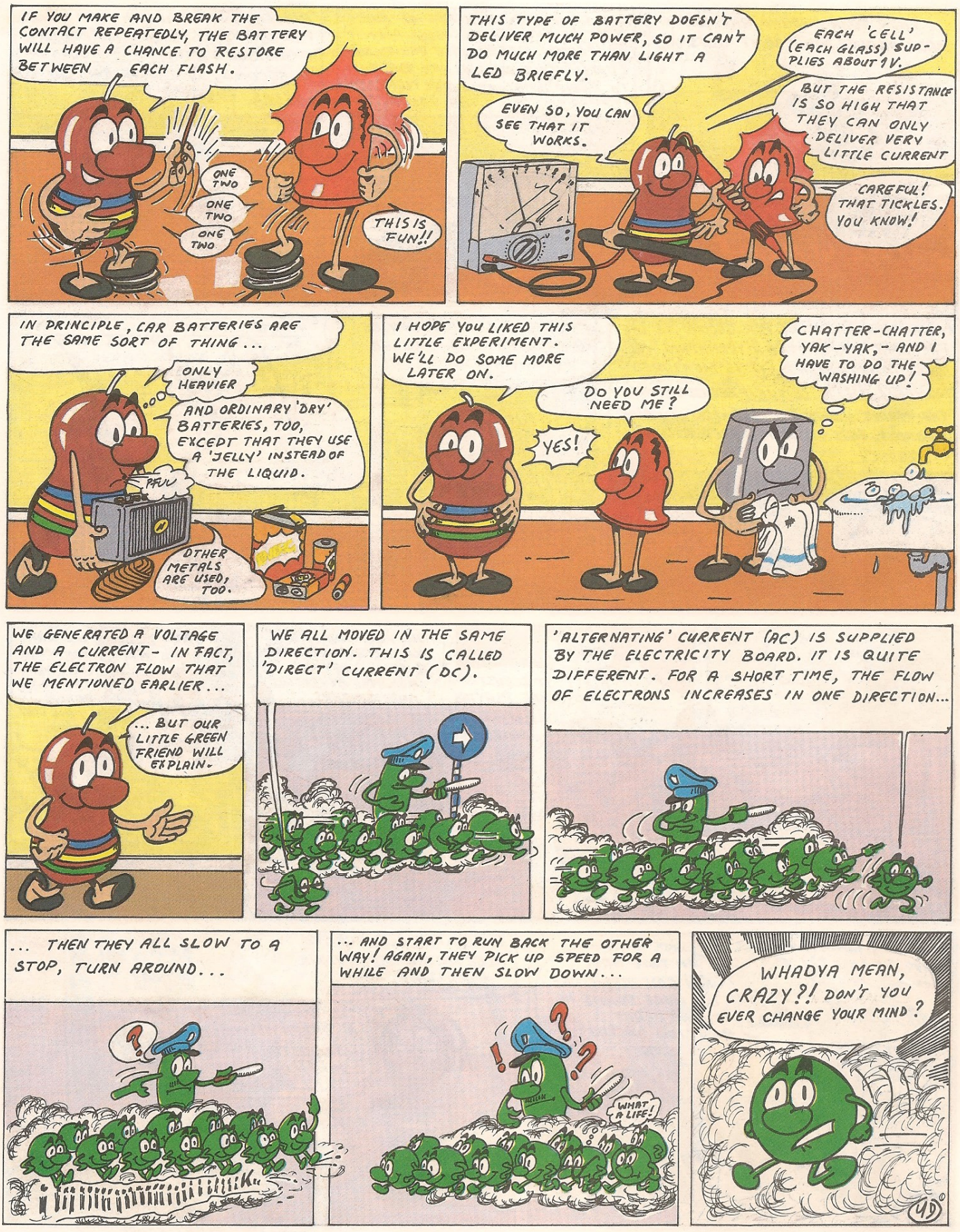

THERE IS A FOURTH VALUE THAT HAS TO BE USED QUITE OFTEN: POWER (P). IT IS MEASURED IN WATTS (W).
LET'S CLEAN UP THE ROOM AND GO BACK TO OUR RIVER.
PLOP!
SLOORP


THESE TWO PADDLE-WHEELS ARE DRIVEN BY TWO WATERFALLS OF THE SAME HEIGHT. BUT MORE WATER IS FLOWING PAST WHEEL TWO, SO THAT WHEEL CAN WORK HARDER - IT CAN DELIVER MORE POWER.
1
2
49

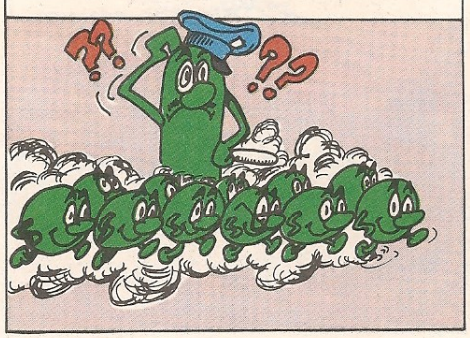

WATER, WATER, EVERYWHERE...!
HERE, THE SAME AMOUNT OF WATER IS FALLING THROUGH BOTH CHANNELS, BUT THE HEIGHTS ARE DIFFERENT. AGAIN, THE SECOND PADDLE-WHEEL WILL BE ABLE TO WORK HARDER.
SO, THE POWER DELIVERED BY THE PADDLE-WHEELS DEPENDS ON TWO FACTORS: LEVEL DIFFERENCE AND FLOW.
ELECTRICITY HAS A SIMILAR LAW: POWER (P) DEPENDS ON VOLTAGE AND CURRENT: P = U × I
DON'T MIX THIS UP WITH OHM'S LAW!!
FOR EXAMPLE: U = I × R — 12 = 2×6; P = U × I — 24 = 12×2. P = 24 WATTS.
P = UI
I = P/U
U = P/I
WHAT IS THE RESISTANCE OF A BULB, RATED AT 220 V AND 100 W ??
EEEEH!
P = 100W U = 220V
I = 100/220 = 0.45A
R = U/I = 220/0.45 = 488Ω
I THINK I GOT IT RIGHT.
BUT, SINCE P = U × I AND U = I × R, YOU CAN WRITE THAT P = I × R × I, OR P = I²R. IN THE SAME WAY: P = U × U/R = U²/R. SEE?
ALL THIS MATHS IS GIVING ME A HEADACHE..
YOU'LL SOON KNOW ALL THESE FORMULAS OFF BY HEART.
WELL, ENOUGH OF THIS. LET'S DO AN INTERESTING EXPERIMENT: 'MAKING ELECTRICITY'!
TRANSI! COME AND HELP!!
YOU ONLY NEED A FEW THINGS FOR THIS...
4 GLASSES OF VINEGAR, 4 ZINC PLATES (1×2 cm) OR BIG NAILS, AND SOME STIFF COPPER WIRE WITH A DIAMETER OF 1,5 mm OR SO.
CHIEF COOK AND BOTTLE-WASHER, THAT'S ME!!
OOPS!
THIS ISN'T EASY!
KLANG
AIE
I KNEW IT WASN'T EASY!!
I'LL SHOW YOU THE MAN WHO INVENTED THE 'VOLTAIC BATTERY!.
I NEEDN'T HAVE BROUGHT ALL THESE VOLUMES, IF RESI HAD TOLD ME HE ONLY WANTED THE LETTER 'V'!
ALESSANDRO VOLTA 1745-1827
VOLTA DIPPED ONE COPPER (CU) AND ONE ZINC (ZN) PLATE INTO SULPHURIC ACID.
49


CAN I DO ANYTHING HERE?
YES, IN A MINUTE..
ENERGY IS RELEASED BY THE ELECTRO-CHEMICAL REACTION. MOST OF THIS ENERGY COMES OUT AS AN ELECTRIC CURRENT.
IS IT MY TURN NOW?
OH DEAR!.. THIS IS RISKY STUFF!
YES, BE PATIENT!!
THIS IS RIDICULOUS! HOW DARE YOU KEEP ME WAITING LIKE THIS?
SILLY GAMES...
MY TURN!
OWW!!
H2SO4 (SULPHURIC ACID) CONSISTS OF: 2 HYDROGEN ATOMS (H), 1 SULPHUR ATOM (S) AND 4 OXYGEN ATOMS (O), ALL STUCK TOGETHER IN EACH 'MOLECULE'.
H, S, O, Cu AND Zn ARE ALL CHEMICAL SYMBOLS.
COMPLETE H2SO4 TEAM
H2SO4 'ATTACKS' THE FREE ELECTRONS IN THE COPPER. SOME OF THEM ESCAPE THROUGH THE WIRE.
BANZAI!!
RUN FOR YOUR LIFE!
BUT H2SO4 LOSES HIS 'H' ATOMS. ONE ESCAPES, THE OTHER GOES TO JOIN THE COPPER.
..3,2,1 - GO!
TRAITORS!
HEY!..
OYY!..
SOME Zn ATOMS 'MAKE FRIENDS' WITH SO4, TO FORM Zn SO4 (ZINC SULPHATE). THIS IS HEAVY STUFF, SO IT SINKS TO THE BOTTOM.
MEANWHILE, THE H ATOMS EITHER FLOAT TO THE SURFACE AND ESCAPE, OR ELSE JOIN THE COPPER.
FREE, AT LAST!
DURING ALL THIS 'UPROAR', THE REACTION PRODUCES A FLOW OF ELECTRONS (CURRENT) FROM ONE PLATE (ELECTRODE) TO THE OTHER.
Zn
Cu
ZnSO4
Zn IS AT A LOWER 'LEVEL' (ELECTRICALLY!) THAN Cu, SO ZINC IS THE NEGATIVE POLE AND COPPER IS THE POSITIVE ONE.
I STILL DON'T SEE WHAT THIS HAS TO DO WITH ME...!
BE QUIET!! FOR HEAVEN'S SAKE!
NOW, LET'S TRY THE SAME EXPERIMENT. WE WON'T USE SULPHURIC ACID - THAT WOULD BE TOO DANGEROUS - BUT VINEGAR WILL DO JUST AS WELL.

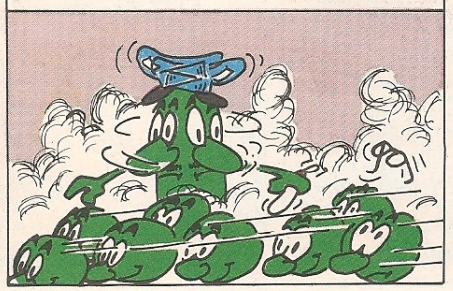

MAKE FOUR SPRINGS BY WINDING SOME BARE COPPER WIRE AROUND A PENCIL (ABOUT 30 cm OF WIRE SHOULD BE ENOUGH FOR EACH).
NOW FLATTEN THEM WITH A HEAVY HAMMER. MIND YOUR FINGERS!
BAM-BAM!
BOM!
I DON'T THINK THIS IS THE RIGHT TIME TO BOTHER HIM..!
NOW, CONNECT A ZINC STRIP OR ZINC NAILS TO...
THREE OF THE FOUR SPRINGS, AND....
BEND THE WIRE LIKE THIS
CONNECT A LENGTH OF WIRE TO THE REMAINING ZINC STRIP AND COPPER SPRING.
NOW ??
NOT YET!!!
I'LL TELL TRANSI ABOUT YOU...
GRRR...
HMPF
DON'T WORRY, I'M NEARLY READY!
PUT EVERYTHING INTO THE FOUR GLASSES, LIKE THIS. MAKE SURE THAT THE TWO WIRES AT THE ENDS DON'T TOUCH.
NOW IT'S TIME FOR LEDY!
BEWARE!!
A LED HAS A ⊕ AND A ⊖ LEAD. THE ⊖ CAN BE INDICATED BY A FLAT SIDE OF THE 'COLLAR', OR BY A SLIGHTLY SHORTER LEAD.
ZINC SIDE ⊖
⊕ COPPER SIDE
THERE IS AN IMMEDIATE REACTION WHEN YOU FILL THE FOUR GLASSES WITH VINEGAR. LEDY WILL LIGHT UP!...
AT LAST!
... BUT THE LED WILL SOON DIM TO A FAINT GLOW. THIS BATTERY LOSES POWER VERY QUICKLY.
OH NO!
45


IF YOU MAKE AND BREAK THE CONTACT REPEATEDLY, THE BATTERY WILL HAVE A CHANCE TO RESTORE BETWEEN EACH FLASH.
ONE TWO
ONE TWO
ONE TWO
THIS IS FUN!!
THIS TYPE OF BATTERY DOESN'T DELIVER MUCH POWER, SO IT CAN'T DO MUCH MORE THAN LIGHT A LED BRIEFLY.
EACH 'CELL' (EACH GLASS) SUPPLIES ABOUT 1V.
BUT THE RESISTANCE IS SO HIGH THAT THEY CAN ONLY DELIVER VERY LITTLE CURRENT
EVEN SO, YOU CAN SEE THAT IT WORKS.
CAREFUL! THAT TICKLES. YOU KNOW!
IN PRINCIPLE, CAR BATTERIES ARE THE SAME SORT OF THING...
ONLY HEAVIER
AND ORDINARY 'DRY' BATTERIES, TOO, EXCEPT THAT THEY USE A 'JELLY' INSTEAD OF THE LIQUID.
PFUU
OTHER METALS ARE USED, TOO.
I HOPE YOU LIKED THIS LITTLE EXPERIMENT. WE'LL DO SOME MORE LATER ON.
DO YOU STILL NEED ME?
YES!
CHATTER-CHATTER, YAK-YAK, - AND I HAVE TO DO THE WASHING UP!
WE GENERATED A VOLTAGE AND A CURRENT - IN FACT, THE ELECTRON FLOW THAT WE MENTIONED EARLIER...
... BUT OUR LITTLE GREEN FRIEND WILL EXPLAIN.
WE ALL MOVED IN THE SAME DIRECTION. THIS IS CALLED 'DIRECT' CURRENT (DC).
'ALTERNATING' CURRENT (AC) IS SUPPLIED BY THE ELECTRICITY BOARD. IT IS QUITE DIFFERENT. FOR A SHORT TIME, THE FLOW OF ELECTRONS INCREASES IN ONE DIRECTION...
... THEN THEY ALL SLOW TO A STOP, TURN AROUND...
... AND START TO RUN BACK THE OTHER WAY! AGAIN, THEY PICK UP SPEED FOR A WHILE AND THEN SLOW DOWN...
WHAT A LIFE!
WHADYA MEAN, CRAZY?! DON'T YOU EVER CHANGE YOUR MIND?

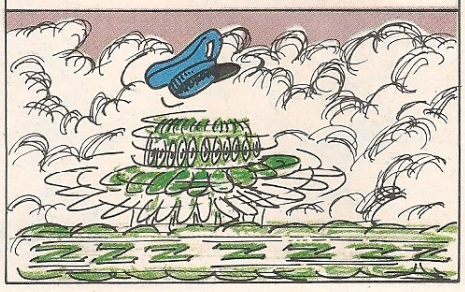
... THEN TURN AROUND AND RUN BACK AGAIN! AND SO IT GOES ON.



ONE COMPLETE SEQUENCE OF RUNNING TO AND FRO IS CALLED A 'CYCLE' OR 'PERIOD'. AFTER EACH PERIOD, THE CURRENT (AND VOLTAGE) ARE BACK TO THEIR ORIGINAL DIRECTION AND VALUE.

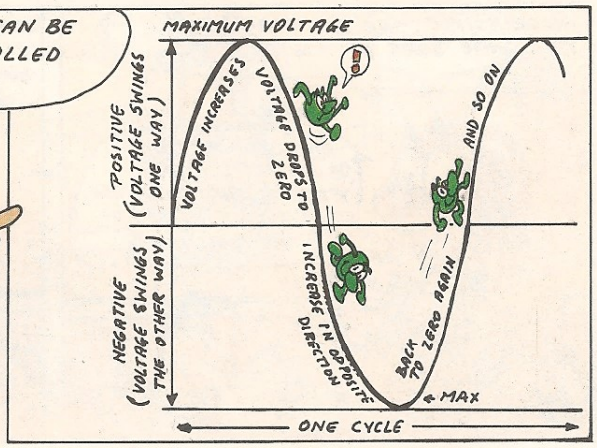


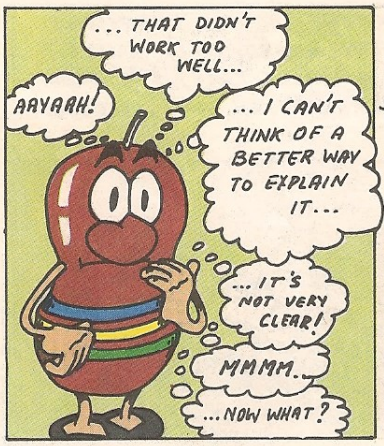
ALL THIS CAN HAPPEN VERY QUICKLY. THE ORDINARY MAINS SUPPLY HAS A 'PERIOD TIME' (T) OF 1/50th OF A SECOND, SO THERE ARE 50 CYCLES EVERY SECOND!

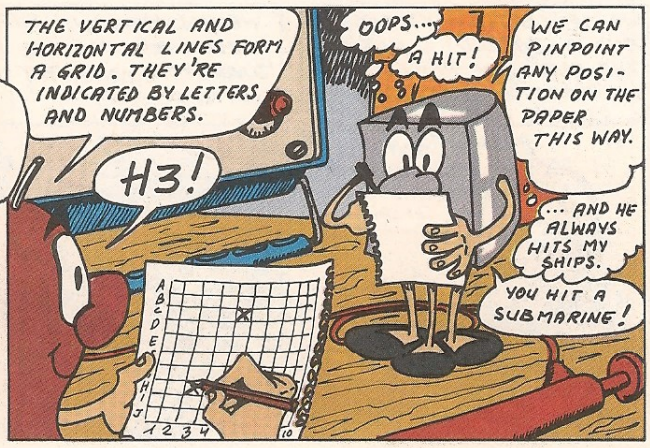


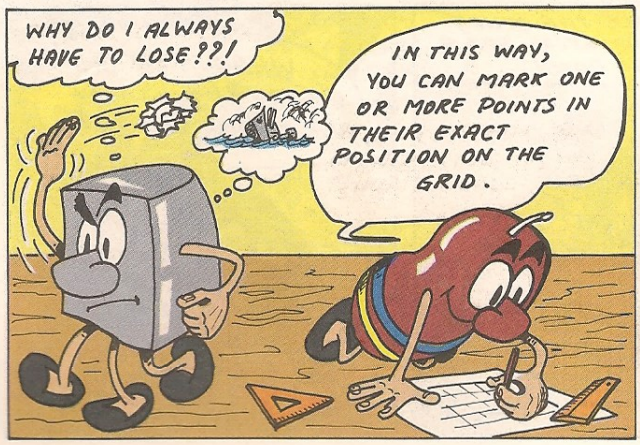
THE NUMBER OF CYCLES PER SECOND IS THE FREQUENCY (F) OF THE ALTERNATING VOLTAGE AND CURRENT. IT IS MEASURED IN HERTZ (Hz), SO THE FREQUENCY OF THE MAINS VOLTAGE IS 50Hz. IN ELECTRONICS, THIS IS CONSIDERED A 'LOW FREQUENCY'.

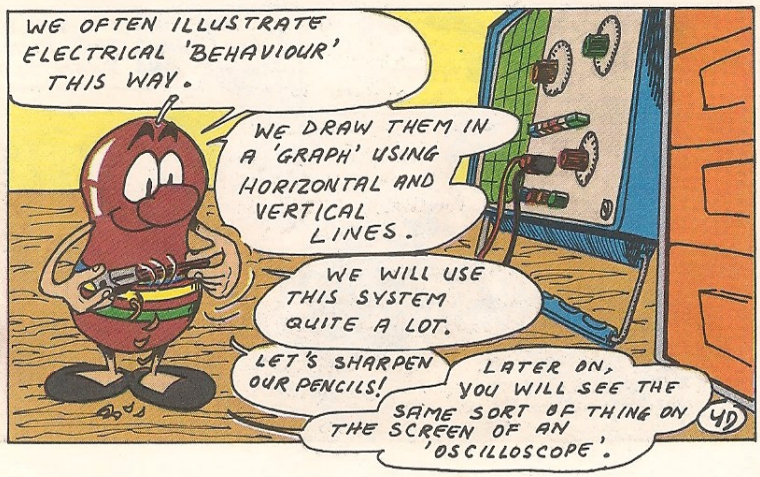
THIS WHOLE THING CAN BE DRAWN, AS A SO-CALLED SINE-WAVE...











IN OUR CASE, THE NUMBERS ALONG THE VERTICAL LINE REPRESENT VOLTS.

VOLTS

ALONG THE HORIZONTAL LINE, THE NUMBERS STAND FOR TIME (IN SECONDS, OR MILLI-SECONDS).

AND NOW FOR THE SQUIGGLY BIT...

TIME

AT EACH POINT IN TIME, WE CAN NOW DRAW THE VOLTAGE. THE RESULT IS A LINE. WE CALL IT A 'CURVE', EVEN WHEN IT'S STRAIGHT!

SUPPOSE THAT ONE CYCLE TAKES 4 MINUTES. WE'LL START OUR MEASUREMENTS AT 12 O'CLOCK. THE VOLTAGE IS ZERO THEN.

V

9V

-9V

(12.H01)

0V (12.H03)

(12.H02)

m

AT 12.01, THE VOLTAGE TURNS OUT TO BE 9V. AT 12.02 IT IS 0V AGAIN, AT 12.03 IT IS -9V. WHAT VOLTAGES WILL WE MEASURE AT 12.04, 12.05 AND 12.07? (DON'T CHEAT!)

STUPID SPORT!

ANSWERS: 0V, +9V, -9V. SEE? IT'S EASY!

MAKING ALTERNATING VOLTAGE IS LIKE MAKING THIS BOWL OF WATER SWING UP AND DOWN IN A REGULAR RHYTHM. THE WATER WILL FLOW TO AND FRO.

+ MAX.

0V

- MAXI

HEY! MR. ARTIST!! HOW DO YOU EXPECT ME TO EXPLAIN THINGS, IF YOU DON'T DRAW ANYTHING FOR ME TO WORK WITH?

WAKE UP!

HE CAN THINK THAT OVER, WHILE WE TAKE A QUICK LOOK AT HOW ELECTRICITY IS DELIVERED FROM A POWER STATION.

WHAT WE NEED AT HOME IS A FAIRLY LOW VOLTAGE (240V) AND LOTS AND LOTS OF CURRENT...

... HOWEVER, A LOT OF ENERGY WOULD BE USED ON THE WAY IF ALL THAT CURRENT HAD TO FLOW DOWN THE WIRES ($P = I^2R$!)

LOW VOLTAGE HEAVY CURRENT

IT'S MUCH BETTER TO USE A VERY HIGH VOLTAGE (THOUSANDS OF VOLTS!) AND A LOW CURRENT, INSTEAD.

HIGH VOLTAGE LOW CURRENT

NEAR OUR HOME, THEY MUST CHANGE THE HIGH VOLTAGE INTO A LOW ONE...

... BY MEANS OF A TRANSFORMER. BUT TRANSFORMERS ONLY WORK ON ALTERNATING CURRENT, SO THAT IS WHAT THE ELECTRICITY BOARD MUST USE.

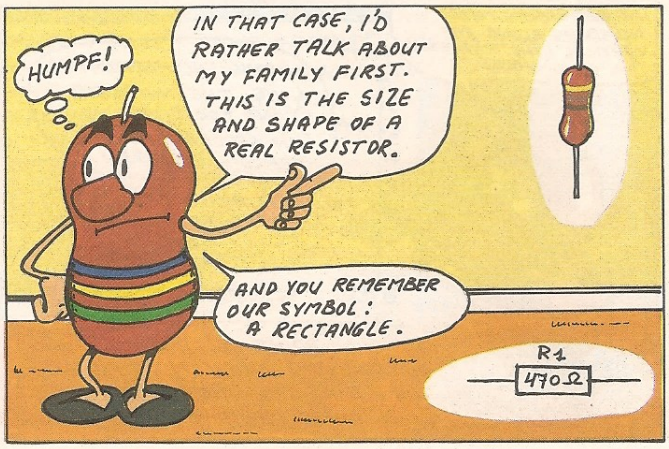
THAT'S ALL I WANTED TO SAY ABOUT THIS.

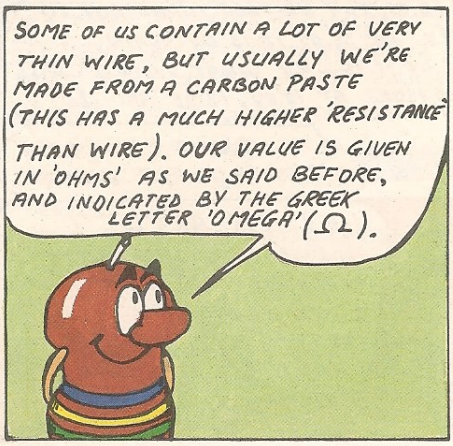
AND NOW IT'S TIME FOR TRANS! TO TELL YOU SOMETHING ABOUT SEMICONDUCTORS.

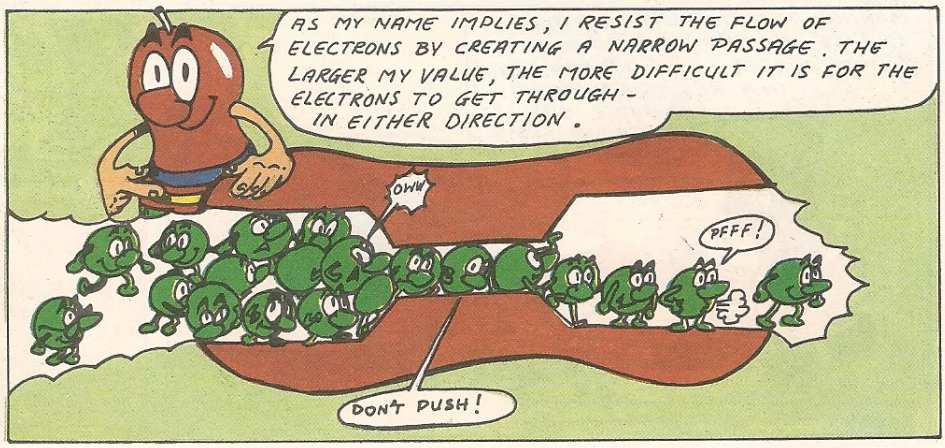
YOU MIGHT AT LEAST WAIT FOR ME TO FINISH CLEANING UP!

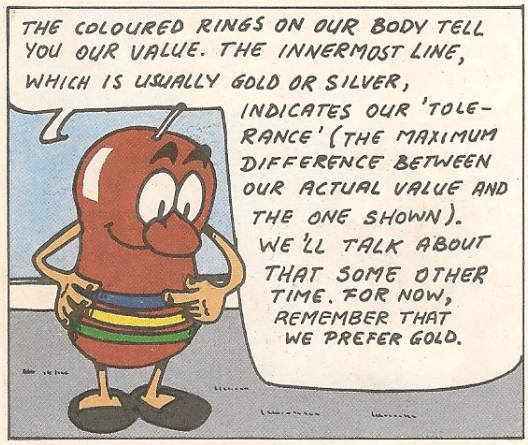
49

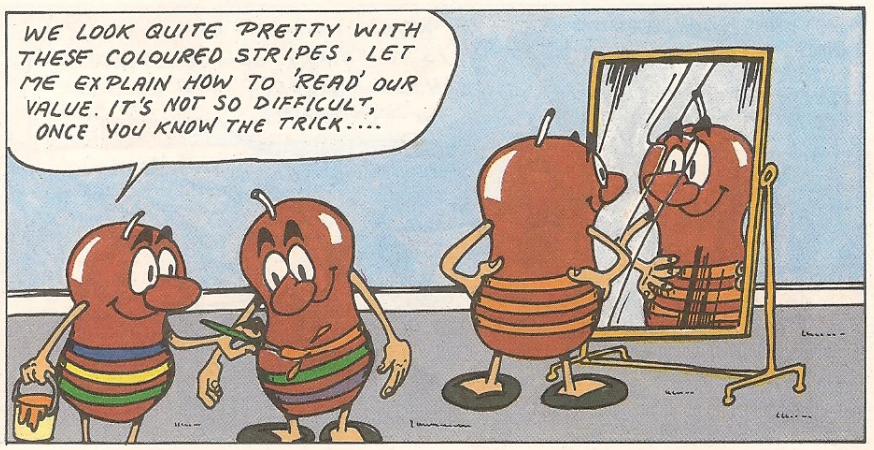

SURELY IT DOESN'T TAKE ALL THAT LONG TO CLEAN THREE GLASSES!?
4!..
... AND ANYWAY, WHY SHOULD I DO ALL THE WORK? I DON'T FEEL LIKE EXPLAINING ANYTHING.
YOU DO IT. I'M BUSY!


HUMPF!
IN THAT CASE, I'D RATHER TALK ABOUT MY FAMILY FIRST. THIS IS THE SIZE AND SHAPE OF A REAL RESISTOR.
AND YOU REMEMBER OUR SYMBOL: A RECTANGLE.
R1
470Ω

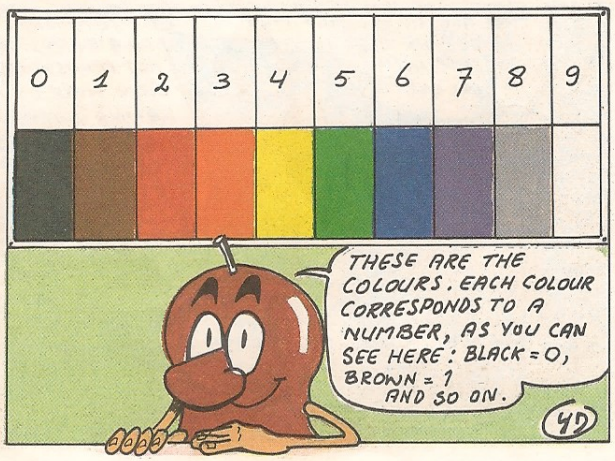

SOME OF US CONTAIN A LOT OF VERY THIN WIRE, BUT USUALLY WE'RE MADE FROM A CARBON PASTE (THIS HAS A MUCH HIGHER 'RESISTANCE' THAN WIRE). OUR VALUE IS GIVEN IN 'OHMS' AS WE SAID BEFORE, AND INDICATED BY THE GREEK LETTER 'OMEGA' (Ω).

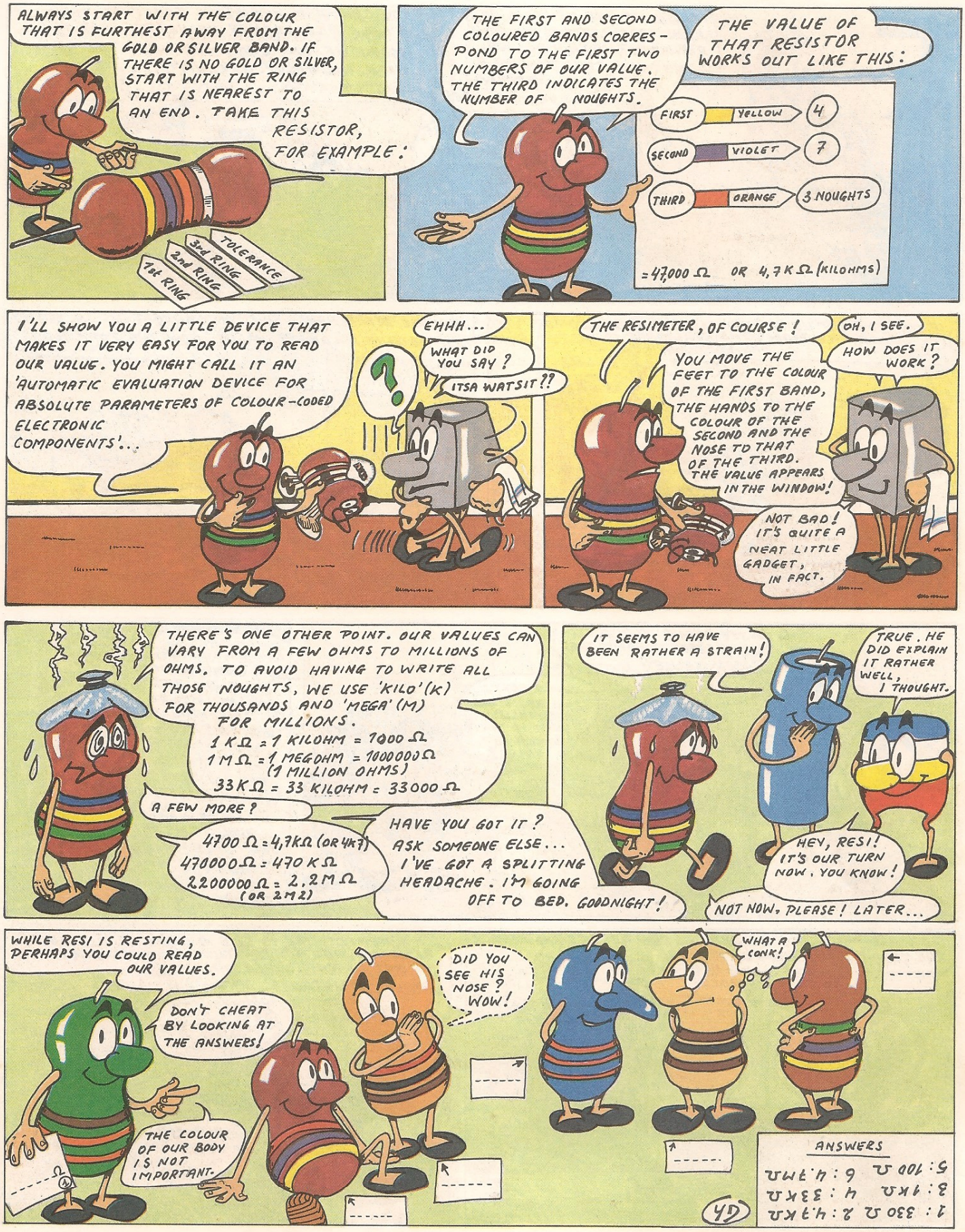

AS MY NAME IMPLIES, I RESIST THE FLOW OF ELECTRONS BY CREATING A NARROW PASSAGE. THE LARGER MY VALUE, THE MORE DIFFICULT IT IS FOR THE ELECTRONS TO GET THROUGH - IN EITHER DIRECTION.
OWW
PFFF!
DON'T PUSH!

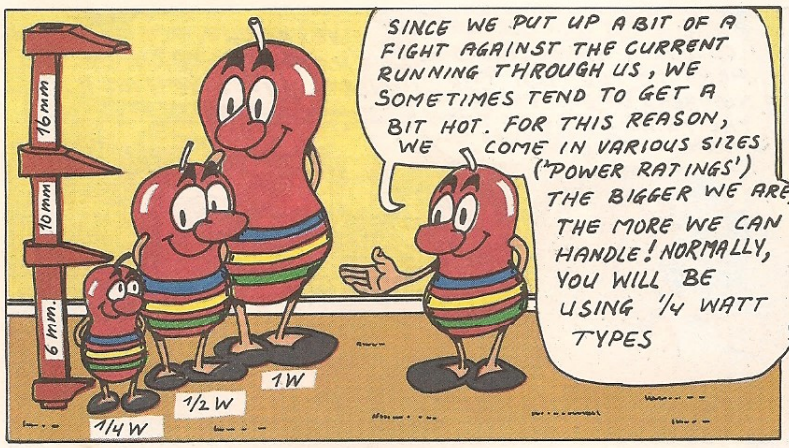

THE COLOURED RINGS ON OUR BODY TELL YOU OUR VALUE. THE INNERMOST LINE, WHICH IS USUALLY GOLD OR SILVER, INDICATES OUR 'TOLERANCE' (THE MAXIMUM DIFFERENCE BETWEEN OUR ACTUAL VALUE AND THE ONE SHOWN). WE'LL TALK ABOUT THAT SOME OTHER TIME. FOR NOW, REMEMBER THAT WE PREFER GOLD.


WE LOOK QUITE PRETTY WITH THESE COLOURED STRIPES. LET ME EXPLAIN HOW TO 'READ' OUR VALUE. IT'S NOT SO DIFFICULT, ONCE YOU KNOW THE TRICK....

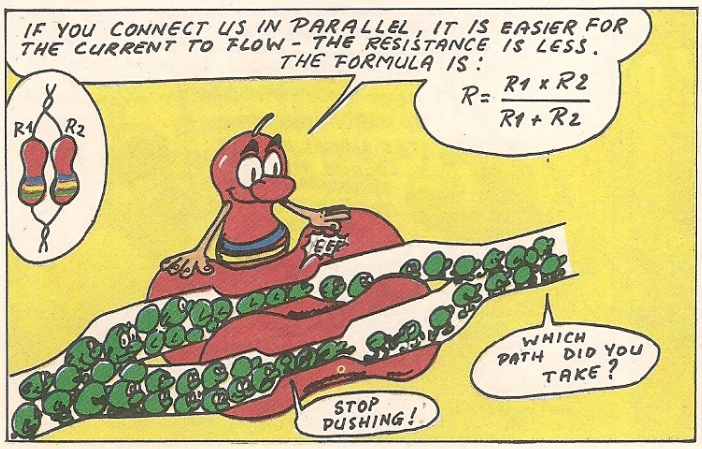

WE USE THE COLOURS OF THE RAINBOW, IN THE SAME ORDER, AND WE ALSO USE BLACK, BROWN, GREY AND WHITE.

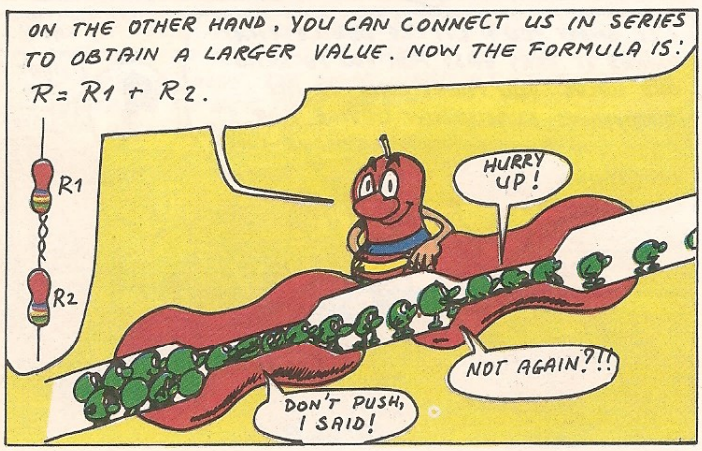

0 1 2 3 4 5 6 7 8 9
THESE ARE THE COLOURS. EACH COLOUR CORRESPONDS TO A NUMBER, AS YOU CAN SEE HERE: BLACK = 0, BROWN = 1 AND SO ON.
4D

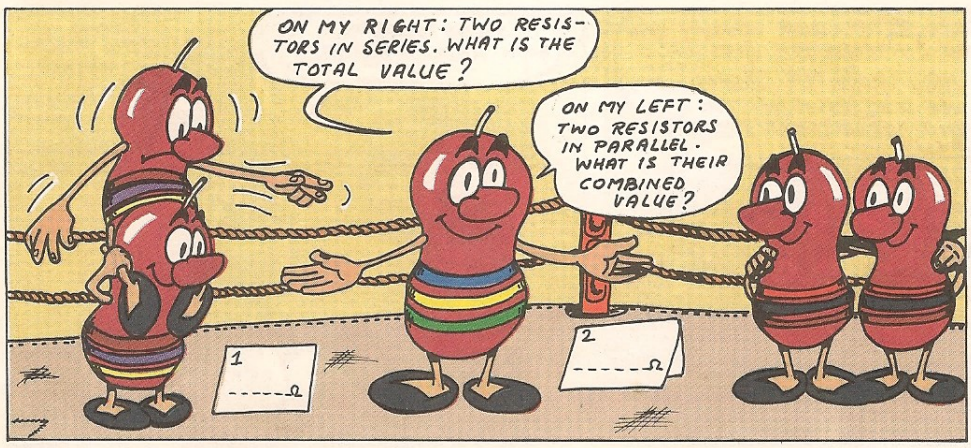

ALWAYS START WITH THE COLOUR THAT IS FURTHEST AWAY FROM THE GOLD OR SILVER BAND. IF THERE IS NO GOLD OR SILVER, START WITH THE RING THAT IS NEAREST TO AN END. TAKE THIS RESISTOR, FOR EXAMPLE:
TOLERANCE
3rd RING
2nd RING
1st RING
THE FIRST AND SECOND COLOURED BANDS CORRESPOND TO THE FIRST TWO NUMBERS OF OUR VALUE. THE THIRD INDICATES THE NUMBER OF NOUGHTS.
THE VALUE OF THAT RESISTOR WORKS OUT LIKE THIS:
FIRST YELLOW 4
SECOND VIOLET 7
THIRD ORANGE 3 NOUGHTS
= 47,000 Ω OR 4,7 KΩ (KILOHMS)
I'LL SHOW YOU A LITTLE DEVICE THAT MAKES IT VERY EASY FOR YOU TO READ OUR VALUE. YOU MIGHT CALL IT AN 'AUTOMATIC EVALUATION DEVICE FOR ABSOLUTE PARAMETERS OF COLOUR-CODED ELECTRONIC COMPONENTS'...
EHHH...
WHAT DID YOU SAY?
ITSA WATSIT??
THE RESIMETER, OF COURSE!
OH, I SEE.
HOW DOES IT WORK?
YOU MOVE THE FEET TO THE COLOUR OF THE FIRST BAND, THE HANDS TO THE COLOUR OF THE SECOND AND THE NOSE TO THAT OF THE THIRD. THE VALUE APPEARS IN THE WINDOW!
NOT BAD! IT'S QUITE A NEAT LITTLE GADGET, IN FACT.
THERE'S ONE OTHER POINT. OUR VALUES CAN VARY FROM A FEW OHMS TO MILLIONS OF OHMS. TO AVOID HAVING TO WRITE ALL THOSE NOUGHTS, WE USE 'KILO' (K) FOR THOUSANDS AND 'MEGA' (M) FOR MILLIONS.
1 KΩ = 1 KILOHM = 1000 Ω
1 MΩ = 1 MEGOHM = 1000000 Ω (1 MILLION OHMS)
33 KΩ = 33 KILOHM = 33000 Ω
A FEW MORE?
4700 Ω = 4,7 KΩ (OR 4K7)
470000 Ω = 470 KΩ
2200000 Ω = 2,2 MΩ (OR 2M2)
HAVE YOU GOT IT? ASK SOMEONE ELSE... I'VE GOT A SPLITTING HEADACHE. I'M GOING OFF TO BED. GOODNIGHT!
IT SEEMS TO HAVE BEEN RATHER A STRAIN!
TRUE. HE DID EXPLAIN IT RATHER WELL, I THOUGHT.
HEY, RESI! IT'S OUR TURN NOW, YOU KNOW!
NOT NOW, PLEASE! LATER...
WHILE RESI IS RESTING, PERHAPS YOU COULD READ OUR VALUES.
DON'T CHEAT BY LOOKING AT THE ANSWERS!
THE COLOUR OF OUR BODY IS NOT IMPORTANT.
DID YOU SEE HIS NOSE? WOW!
WHAT A CONK!
ANSWERS
1: 330 Ω 2: 4,7 KΩ
3: 1 KΩ 4: 33 KΩ
5: 100 Ω 6: 4,7 MΩ

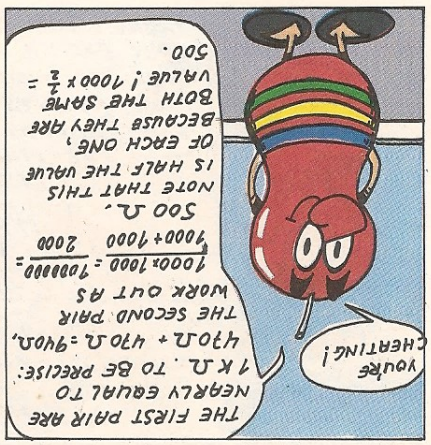

SINCE WE PUT UP A BIT OF A FIGHT AGAINST THE CURRENT RUNNING THROUGH US, WE SOMETIMES TEND TO GET A BIT HOT. FOR THIS REASON, WE COME IN VARIOUS SIZES ('POWER RATINGS') THE BIGGER WE ARE, THE MORE WE CAN HANDLE! NORMALLY, YOU WILL BE USING 1/4 WATT TYPES
16 mm
10 mm
6 mm
1/4 W
1/2 W
1W

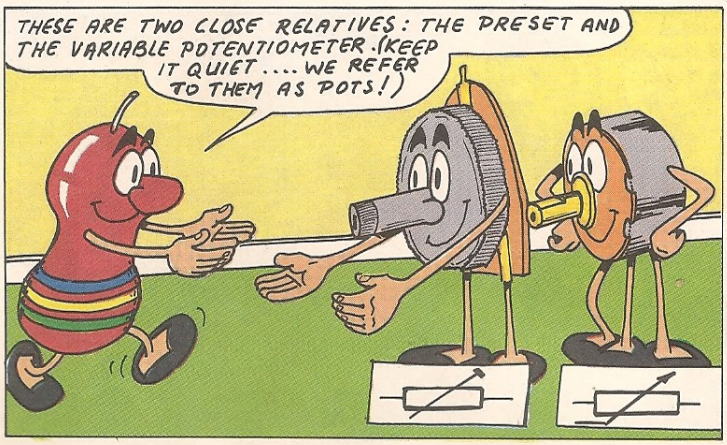

YOU CAN JOIN RESISTORS TOGETHER TO MAKE A NEW RESISTANCE VALUE (R). THIS IS USEFUL IF YOU CAN'T FIND ONE OF US WITH THE VALUE YOU WANT.

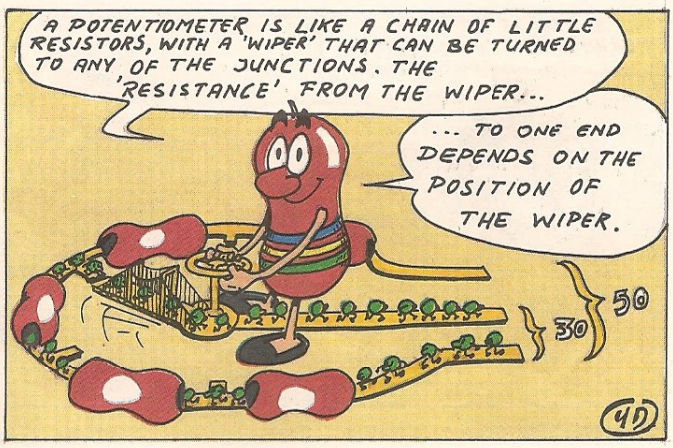

IF YOU CONNECT US IN PARALLEL, IT IS EASIER FOR THE CURRENT TO FLOW - THE RESISTANCE IS LESS. THE FORMULA IS:
$R = \frac{R1 \times R2}{R1 + R2}$
R1
R2
EEE
WHICH PATH DID YOU TAKE?
STOP PUSHING!


ON THE OTHER HAND, YOU CAN CONNECT US IN SERIES TO OBTAIN A LARGER VALUE. NOW THE FORMULA IS:
$R = R1 + R2$.
R1
R2
HURRY UP!
NOT AGAIN?!!
DON'T PUSH, I SAID!


ON MY RIGHT: TWO RESISTORS IN SERIES. WHAT IS THE TOTAL VALUE?
ON MY LEFT: TWO RESISTORS IN PARALLEL. WHAT IS THEIR COMBINED VALUE?
1
Ω
2
Ω


YOU'RE CHEATING!
THE FIRST PAIR ARE NEARLY EQUAL TO 1 KΩ. TO BE PRECISE: 470Ω + 470Ω = 940Ω, THE SECOND PAIR WORK OUT AS
$\frac{1000 \times 1000}{1000 + 1000} = \frac{1000000}{2000}$ =
500 Ω.
NOTE THAT THIS IS HALF THE VALUE OF EACH ONE, BECAUSE THEY ARE BOTH THE SAME VALUE! $1000 \times \frac{1}{2}$ = 500.


THESE ARE TWO CLOSE RELATIVES: THE PRESET AND THE VARIABLE POTENTIOMETER. (KEEP IT QUIET.... WE REFER TO THEM AS POTS!)


A POTENTIOMETER IS LIKE A CHAIN OF LITTLE RESISTORS, WITH A 'WIPER' THAT CAN BE TURNED TO ANY OF THE JUNCTIONS. THE 'RESISTANCE' FROM THE WIPER...
... TO ONE END DEPENDS ON THE POSITION OF THE WIPER.
30
50
4D

I HAVE SEVERAL MORE RELATIVES: PRECISION RESISTORS, LDRS THAT ARE SENSITIVE TO LIGHT, NTCS AND PTCS THAT ARE SENSITIVE TO TEMPERATURE, VDRS THAT VARY WITH THE VOLTAGE, AND SO ON. IT'S A LONG LIST, BUT THERE IS NO POINT IN INTRODUCING THEM ALL NOW.

YOU'VE GOT TO KNOW WHEN TO STOP! FOR THAT MATTER, I HARDLY EVER SEE THEM...

TIME FOR ANOTHER EXPERIMENT. WE WON'T USE SOLDER YET, BECAUSE WE WANT TO RE-USE THESE COMPONENTS LATER ON.

YOU'LL NEED A 9V BATTERY, TWO 1KΩ RESISTORS - AND LEDY, OF COURSE!

FIRST STEP: CONNECT THE LED AND ONE RESISTOR IN SERIES ACROSS THE BATTERY. MAKE SURE LEDY IS THE RIGHT WAY ROUND - AND DON'T CONNECT HER STRAIGHT ACROSS THE BATTERY!

9V

4K

R

LEDY WILL LIGHT. SHE LOVES THE LIMELIGHT!

NOW TRY CONNECTING TWO RESISTORS OF 1KΩ IN SERIES WITH THE LED.

R1 1K

R2 1K

THE TOTAL RESISTANCE IS 2KΩ, SO THE CURRENT IS HALVED AND THE LED WILL BE DIMMER.

NEXT, CONNECT THE TWO RESISTORS IN PARALLEL - AS SHOWN HERE. THIS GIVES A TOTAL RESISTANCE:

$R = \frac{1K \times 1K}{1K + 1K} = \frac{1}{2}K\Omega = 500\Omega.$

1K

1K

R1

R2

LESS RESISTANCE MEANS MORE CURRENT: LEDY WILL SHINE QUITE BRIGHTLY!

HAVING SEEN HOW THIS LITTLE CIRCUIT WORKS, WE CAN MOUNT IT ON THE PRINTED CIRCUIT BOARD. WE WILL USE IT QUITE OFTEN...

... FROM NOW ON.

WIRE 10cm (4")

WIRE 10cm (4")

(TEST LEADS)

COMPONENT LAYOUT

WHAT DOES IT DO? WE CAN USE IT AS A 'CONTINUITY TESTER' TO SEE IF TWO POINTS ARE CONNECTED. FOR INSTANCE, WE CAN CHECK THIS TORCH BULB. TOUCH THE WIRES TO THE TWO CONTACTS: IF THE LED LIGHTS, THE BULB IS OK. IF THE LED DOESN'T LIGHT, THE BULB IS DUD...

... OR ELSE YOU FORGOT THE BATTERY!

WHAT A TALKER!

YES, BUT IT'S ALL ABOUT RESISTORS...

HEY, RESI! WHAT ABOUT US?

SURELY YOU CAN INTRODUCE YOUR OWN FAMILY!

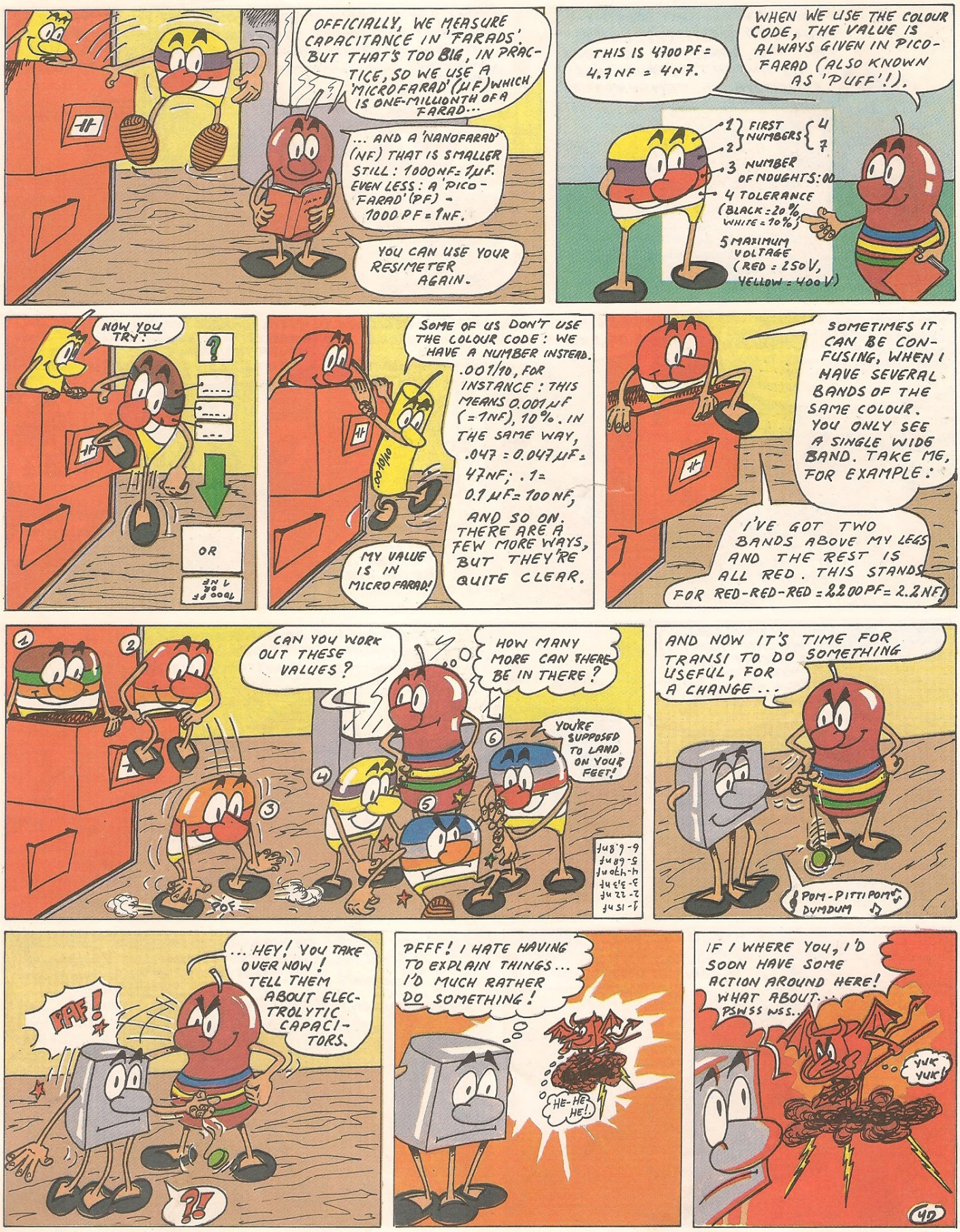
BUT YOU'RE MUCH BETTER AT IT, RESI!

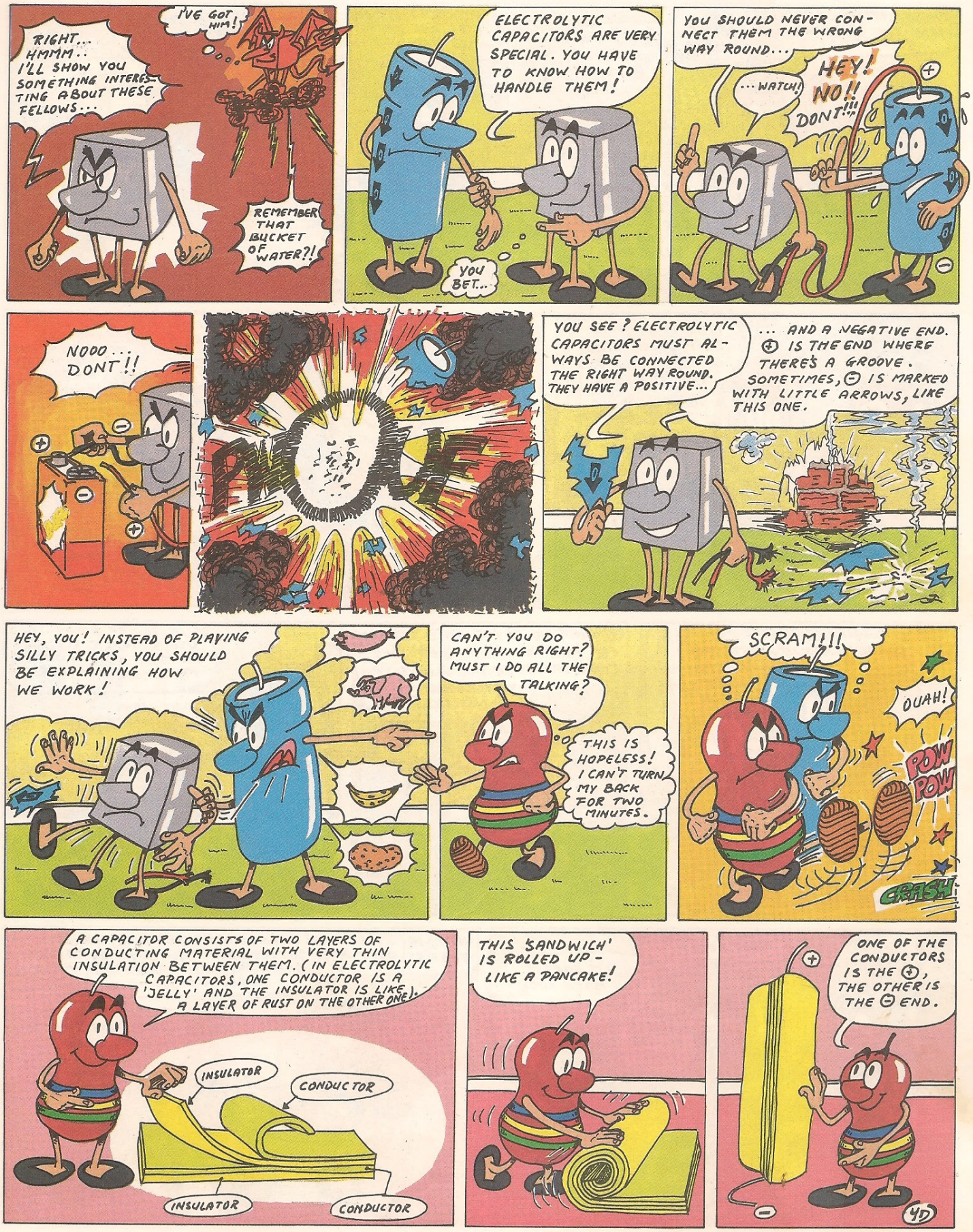
HOW FLATTERING! BUT IT MEANS THAT I DO ALL THE WORK.

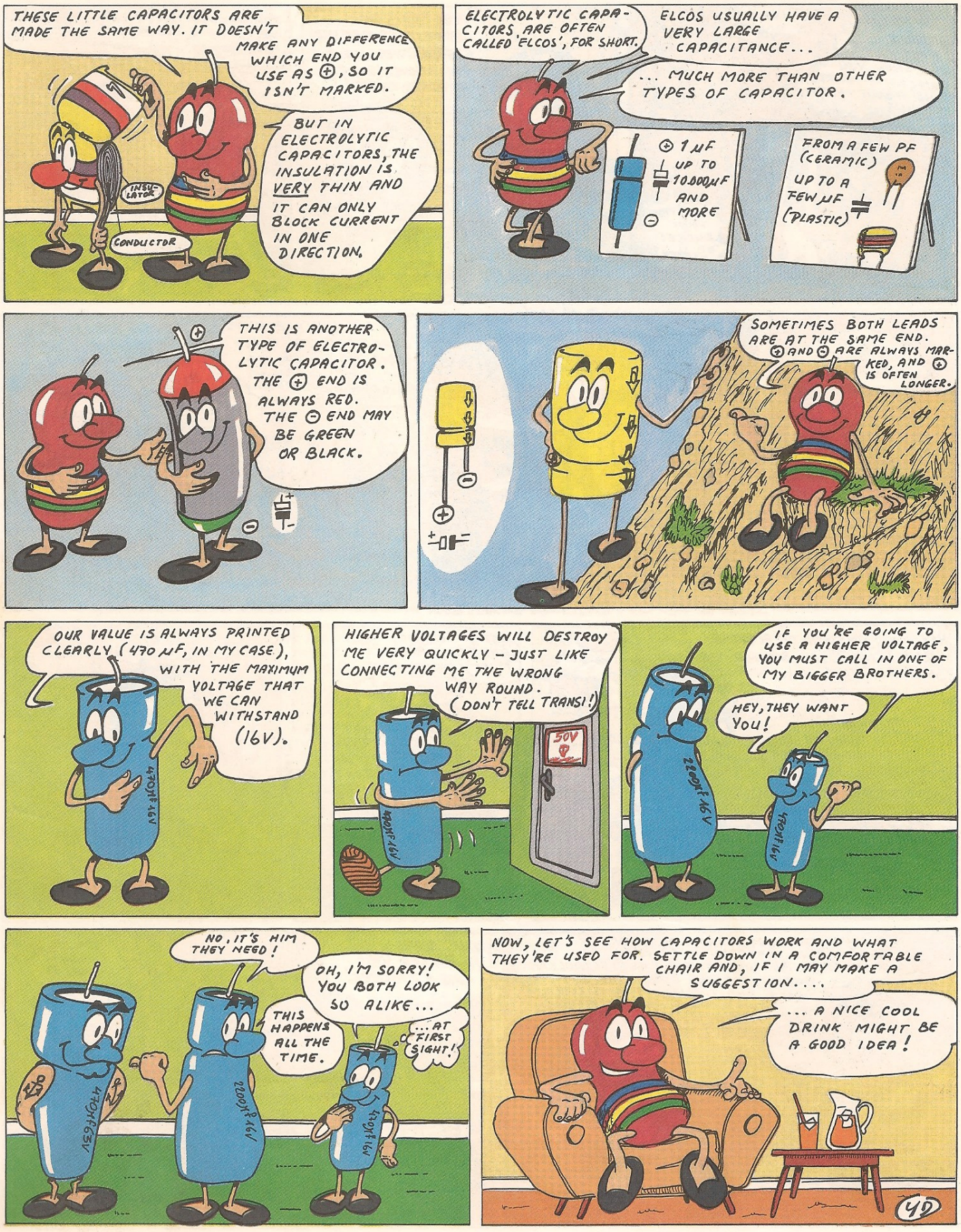
OH WELL. LET'S SEE - HOW CAN I EXPLAIN THE CAPACITORS?

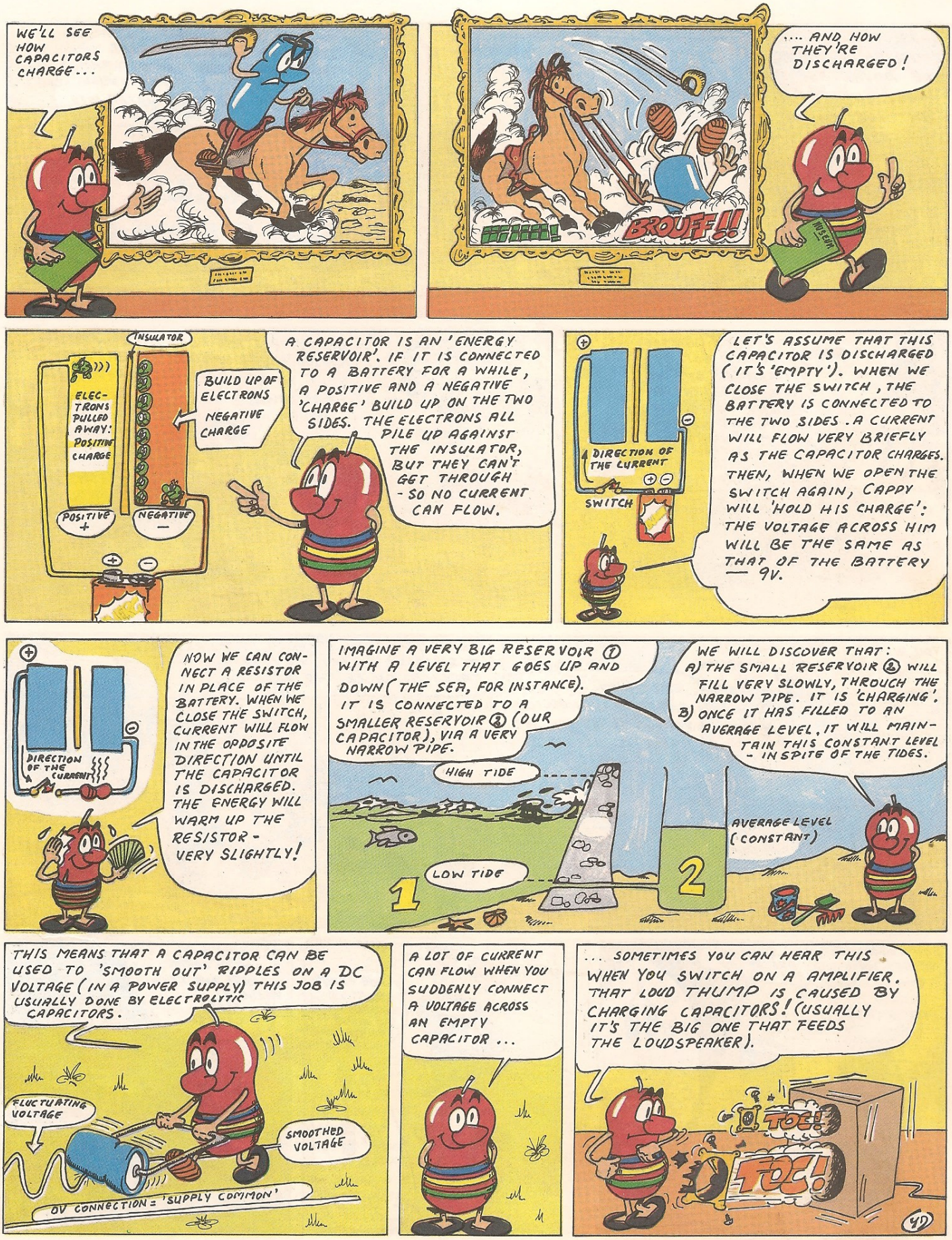
I COULD COMPARE THEM WITH STORAGE TANKS...

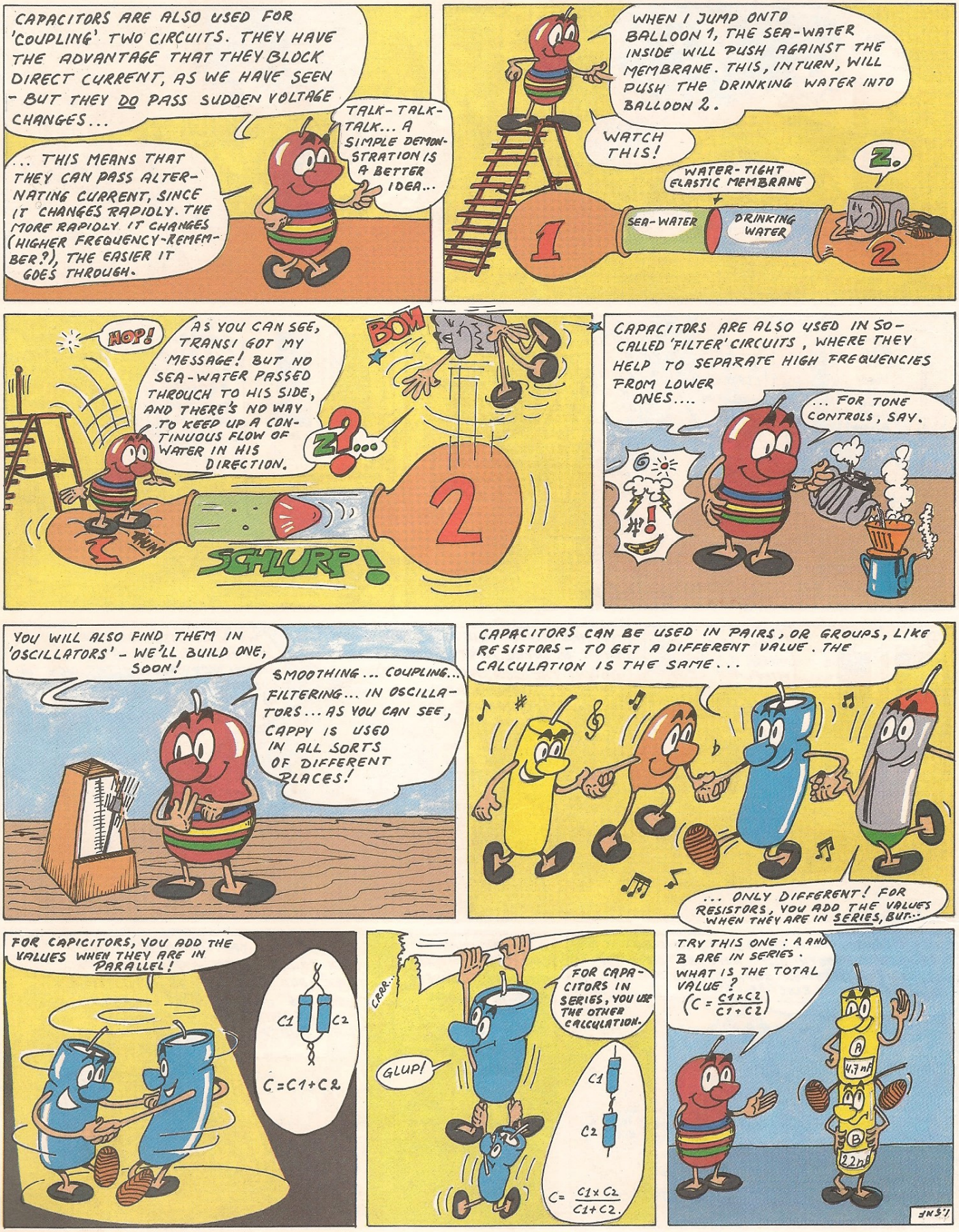
CAPACITORS HAVE STORAGE CAPACITY FOR ELECTRICAL ENERGY.

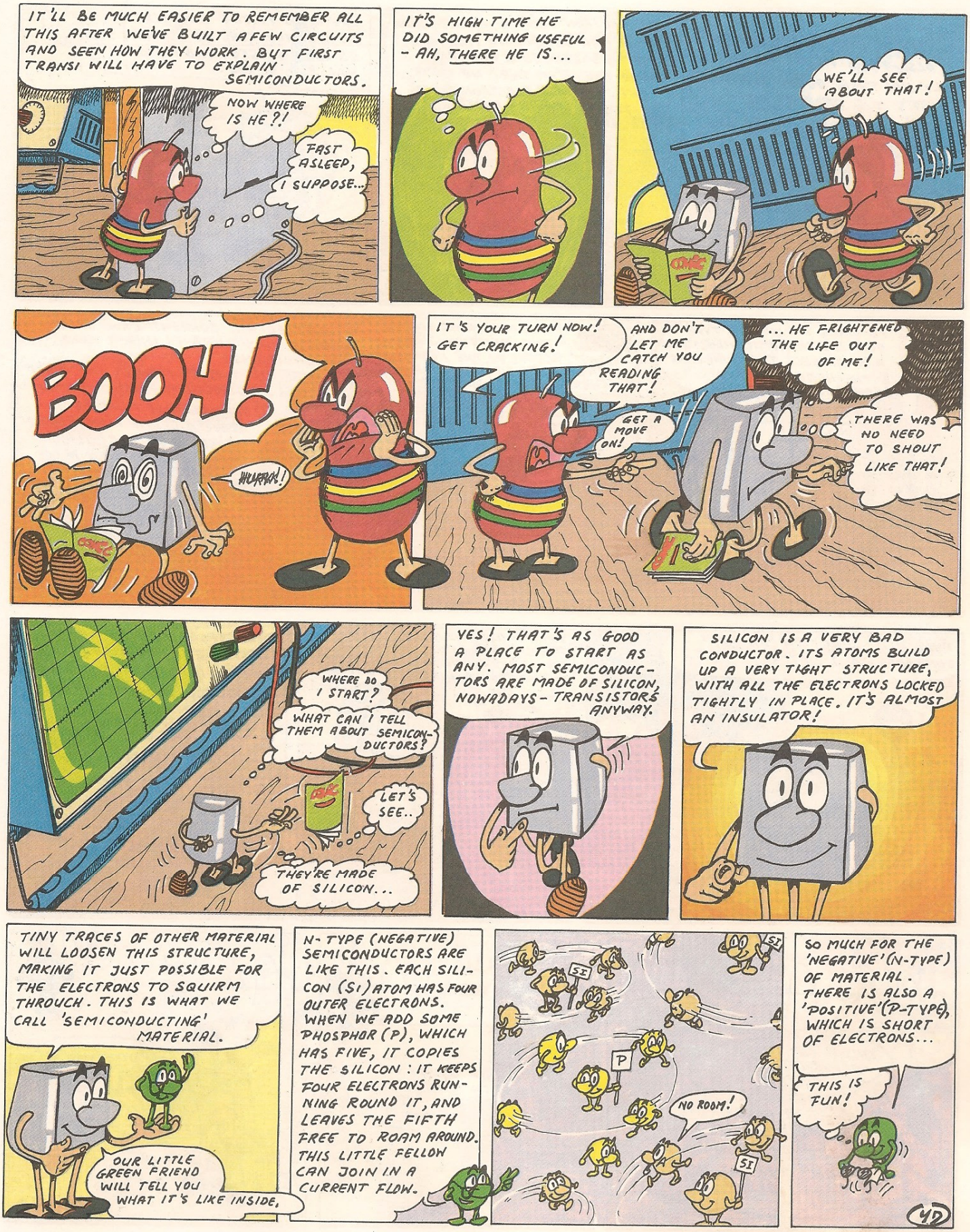

OFFICIALLY, WE MEASURE CAPACITANCE IN 'FARADS'. BUT THAT'S TOO BIG, IN PRACTICE, SO WE USE A 'MICROFARAD' (µF) WHICH IS ONE-MILLIONTH OF A FARAD...
... AND A 'NANOFARAD' (NF) THAT IS SMALLER STILL: 1000NF = 1µF. EVEN LESS: A 'PICOFARAD' (PF) = 1000 PF = 1NF.
YOU CAN USE YOUR RESIMETER AGAIN.
THIS IS 4700 PF = 4.7 NF = 4N7.
WHEN WE USE THE COLOUR CODE, THE VALUE IS ALWAYS GIVEN IN PICOFARAD (ALSO KNOWN AS 'PUFF'!).
1 } FIRST NUMBERS { 4 7
2
3 NUMBER OF NOUGHTS: 00
4 TOLERANCE (BLACK = 20% WHITE = 10%)
5 MAXIMUM VOLTAGE (RED = 250V, YELLOW = 400V)
NOW YOU TRY!
OR
SOME OF US DON'T USE THE COLOUR CODE: WE HAVE A NUMBER INSTEAD. .001/10, FOR INSTANCE: THIS MEANS 0.001 µF (= 1NF), 10%. IN THE SAME WAY, .047 = 0.047 µF = 47NF; .1 = 0.1 µF = 100 NF, AND SO ON. THERE ARE A FEW MORE WAYS, BUT THEY'RE QUITE CLEAR.
.001/10
MY VALUE IS IN MICROFARAD!
SOMETIMES IT CAN BE CONFUSING, WHEN I HAVE SEVERAL BANDS OF THE SAME COLOUR. YOU ONLY SEE A SINGLE WIDE BAND. TAKE ME, FOR EXAMPLE:
I'VE GOT TWO BANDS ABOVE MY LEGS AND THE REST IS ALL RED. THIS STANDS FOR RED-RED-RED = 2200 PF = 2.2 NF)
CAN YOU WORK OUT THESE VALUES?
HOW MANY MORE CAN THERE BE IN THERE?
YOU'RE SUPPOSED TO LAND ON YOUR FEET!
1- 15 nF
2- 22 nF
3- 3.3 nF
4- 470 nF
5- 68 nF
6- 6.8 nF
POF
AND NOW IT'S TIME FOR TRANSI TO DO SOMETHING USEFUL, FOR A CHANGE...
POM-PITTI POM DUMDUM
... HEY! YOU TAKE OVER NOW! TELL THEM ABOUT ELECTROLYTIC CAPACITORS.
PAF!
?!
PFFF! I HATE HAVING TO EXPLAIN THINGS... I'D MUCH RATHER DO SOMETHING!
HE-HE-HE!
IF I WHERE YOU, I'D SOON HAVE SOME ACTION AROUND HERE! WHAT ABOUT... PSWSS WSS...
YUK YUK!
4D


RIGHT... HMMM.. I'LL SHOW YOU SOMETHING INTERESTING ABOUT THESE FELLOWS...
I'VE GOT HIM!
REMEMBER THAT BUCKET OF WATER?!
ELECTROLYTIC CAPACITORS ARE VERY SPECIAL. YOU HAVE TO KNOW HOW TO HANDLE THEM!
YOU BET...
YOU SHOULD NEVER CONNECT THEM THE WRONG WAY ROUND...
... WATCH!
HEY! NO!! DONT!!!
NOOO... DONT!!
YOU SEE? ELECTROLYTIC CAPACITORS MUST ALWAYS BE CONNECTED THE RIGHT WAY ROUND. THEY HAVE A POSITIVE...
... AND A NEGATIVE END. ⊕ IS THE END WHERE THERE'S A GROOVE. SOMETIMES, ⊖ IS MARKED WITH LITTLE ARROWS, LIKE THIS ONE.
HEY, YOU! INSTEAD OF PLAYING SILLY TRICKS, YOU SHOULD BE EXPLAINING HOW WE WORK!
CAN'T YOU DO ANYTHING RIGHT? MUST I DO ALL THE TALKING?
THIS IS HOPELESS! I CAN'T TURN MY BACK FOR TWO MINUTES.
SCRAM!!!
OUAH!
POW POW
CRASH
A CAPACITOR CONSISTS OF TWO LAYERS OF CONDUCTING MATERIAL WITH VERY THIN INSULATION BETWEEN THEM. (IN ELECTROLYTIC CAPACITORS, ONE CONDUCTOR IS A 'JELLY' AND THE INSULATOR IS LIKE A LAYER OF RUST ON THE OTHER ONE).
INSULATOR
CONDUCTOR
INSULATOR
CONDUCTOR
THIS 'SANDWICH' IS ROLLED UP - LIKE A PANCAKE!
ONE OF THE CONDUCTORS IS THE ⊕, THE OTHER IS THE ⊖ END.
YD


THESE LITTLE CAPACITORS ARE MADE THE SAME WAY. IT DOESN'T MAKE ANY DIFFERENCE WHICH END YOU USE AS ⊕, SO IT ISN'T MARKED.
INSULATOR
CONDUCTOR
BUT IN ELECTROLYTIC CAPACITORS, THE INSULATION IS VERY THIN AND IT CAN ONLY BLOCK CURRENT IN ONE DIRECTION.
ELECTROLYTIC CAPACITORS ARE OFTEN CALLED 'ELCOS', FOR SHORT.
ELCOS USUALLY HAVE A VERY LARGE CAPACITANCE...
... MUCH MORE THAN OTHER TYPES OF CAPACITOR.
⊕ 1 µF UP TO 10,000 µF AND MORE
⊖
FROM A FEW PF (CERAMIC) UP TO A FEW µF (PLASTIC)
THIS IS ANOTHER TYPE OF ELECTROLYTIC CAPACITOR. THE ⊕ END IS ALWAYS RED. THE ⊖ END MAY BE GREEN OR BLACK.
SOMETIMES BOTH LEADS ARE AT THE SAME END. ⊕ AND ⊖ ARE ALWAYS MARKED, AND ⊕ IS OFTEN LONGER.
OUR VALUE IS ALWAYS PRINTED CLEARLY (470 µF, IN MY CASE), WITH THE MAXIMUM VOLTAGE THAT WE CAN WITHSTAND (16V).
HIGHER VOLTAGES WILL DESTROY ME VERY QUICKLY – JUST LIKE CONNECTING ME THE WRONG WAY ROUND. (DON'T TELL TRANS!)
50V
IF YOU'RE GOING TO USE A HIGHER VOLTAGE, YOU MUST CALL IN ONE OF MY BIGGER BROTHERS.
HEY, THEY WANT YOU!
NO, IT'S HIM THEY NEED!
OH, I'M SORRY! YOU BOTH LOOK SO ALIKE...
THIS HAPPENS ALL THE TIME.
... AT FIRST SIGHT!
NOW, LET'S SEE HOW CAPACITORS WORK AND WHAT THEY'RE USED FOR. SETTLE DOWN IN A COMFORTABLE CHAIR AND, IF I MAY MAKE A SUGGESTION....
... A NICE COOL DRINK MIGHT BE A GOOD IDEA!
YD


WE'LL SEE HOW CAPACITORS CHARGE...
.... AND HOW THEY'RE DISCHARGED!
BROUFF!!
INSULATOR
ELECTRONS PULLED AWAY: POSITIVE CHARGE
BUILD UP OF ELECTRONS NEGATIVE CHARGE
POSITIVE +
NEGATIVE —
A CAPACITOR IS AN 'ENERGY RESERVOIR'. IF IT IS CONNECTED TO A BATTERY FOR A WHILE, A POSITIVE AND A NEGATIVE 'CHARGE' BUILD UP ON THE TWO SIDES. THE ELECTRONS ALL PILE UP AGAINST THE INSULATOR, BUT THEY CAN'T GET THROUGH - SO NO CURRENT CAN FLOW.
DIRECTION OF THE CURRENT
SWITCH
LET'S ASSUME THAT THIS CAPACITOR IS DISCHARGED (IT'S 'EMPTY'). WHEN WE CLOSE THE SWITCH, THE BATTERY IS CONNECTED TO THE TWO SIDES. A CURRENT WILL FLOW VERY BRIEFLY AS THE CAPACITOR CHARGES. THEN, WHEN WE OPEN THE SWITCH AGAIN, CAPPY WILL 'HOLD HIS CHARGE': THE VOLTAGE ACROSS HIM WILL BE THE SAME AS THAT OF THE BATTERY — 9V.
DIRECTION OF THE CURRENT
NOW WE CAN CONNECT A RESISTOR IN PLACE OF THE BATTERY. WHEN WE CLOSE THE SWITCH, CURRENT WILL FLOW IN THE OPPOSITE DIRECTION UNTIL THE CAPACITOR IS DISCHARGED. THE ENERGY WILL WARM UP THE RESISTOR - VERY SLIGHTLY!
IMAGINE A VERY BIG RESERVOIR (1) WITH A LEVEL THAT GOES UP AND DOWN (THE SEA, FOR INSTANCE). IT IS CONNECTED TO A SMALLER RESERVOIR (2) (OUR CAPACITOR), VIA A VERY NARROW PIPE.
WE WILL DISCOVER THAT:
A) THE SMALL RESERVOIR (2) WILL FILL VERY SLOWLY, THROUGH THE NARROW PIPE. IT IS 'CHARGING'.
B) ONCE IT HAS FILLED TO AN AVERAGE LEVEL, IT WILL MAINTAIN THIS CONSTANT LEVEL - IN SPITE OF THE TIDES.
HIGH TIDE
LOW TIDE
AVERAGE LEVEL (CONSTANT)
1
2
THIS MEANS THAT A CAPACITOR CAN BE USED TO 'SMOOTH OUT' RIPPLES ON A DC VOLTAGE (IN A POWER SUPPLY) THIS JOB IS USUALLY DONE BY ELECTROLYTIC CAPACITORS.
FLUCTUATING VOLTAGE
SMOOTHED VOLTAGE
0V CONNECTION = 'SUPPLY COMMON'
A LOT OF CURRENT CAN FLOW WHEN YOU SUDDENLY CONNECT A VOLTAGE ACROSS AN EMPTY CAPACITOR ...
... SOMETIMES YOU CAN HEAR THIS WHEN YOU SWITCH ON A AMPLIFIER. THAT LOUD THUMP IS CAUSED BY CHARGING CAPACITORS! (USUALLY IT'S THE BIG ONE THAT FEEDS THE LOUDSPEAKER).
TOC!
TOC!
4D


CAPACITORS ARE ALSO USED FOR 'COUPLING' TWO CIRCUITS. THEY HAVE THE ADVANTAGE THAT THEY BLOCK DIRECT CURRENT, AS WE HAVE SEEN - BUT THEY DO PASS SUDDEN VOLTAGE CHANGES...
... THIS MEANS THAT THEY CAN PASS ALTERNATING CURRENT, SINCE IT CHANGES RAPIDLY. THE MORE RAPIDLY IT CHANGES (HIGHER FREQUENCY-REMEMBER?), THE EASIER IT GOES THROUGH.
TALK-TALK-TALK... A SIMPLE DEMONSTRATION IS A BETTER IDEA...
WHEN I JUMP ONTO BALLOON 1, THE SEA-WATER INSIDE WILL PUSH AGAINST THE MEMBRANE. THIS, IN TURN, WILL PUSH THE DRINKING WATER INTO BALLOON 2.
WATCH THIS!
WATER-TIGHT ELASTIC MEMBRANE
SEA-WATER
DRINKING WATER
1
2
HOP!
AS YOU CAN SEE, TRANSI GOT MY MESSAGE! BUT NO SEA-WATER PASSED THROUCH TO HIS SIDE, AND THERE'S NO WAY TO KEEP UP A CONTINUOUS FLOW OF WATER IN HIS DIRECTION.
BOM
Z?...
SCHLURP!
CAPACITORS ARE ALSO USED IN SO-CALLED 'FILTER' CIRCUITS, WHERE THEY HELP TO SEPARATE HIGH FREQUENCIES FROM LOWER ONES....
... FOR TONE CONTROLS, SAY.
YOU WILL ALSO FIND THEM IN 'OSCILLATORS' - WE'LL BUILD ONE, SOON!
SMOOTHING... COUPLING... FILTERING... IN OSCILLATORS... AS YOU CAN SEE, CAPPY IS USED IN ALL SORTS OF DIFFERENT PLACES!
CAPACITORS CAN BE USED IN PAIRS, OR GROUPS, LIKE RESISTORS - TO GET A DIFFERENT VALUE. THE CALCULATION IS THE SAME...
... ONLY DIFFERENT! FOR RESISTORS, YOU ADD THE VALUES WHEN THEY ARE IN SERIES, BUT...
FOR CAPICITORS, YOU ADD THE VALUES WHEN THEY ARE IN PARALLEL!
C1
C2
C=C1+C2
CRRR...
GLUP!
FOR CAPACITORS IN SERIES, YOU USE THE OTHER CALCULATION.
C1
C2
C= C1×C2 / C1+C2.
TRY THIS ONE: A AND B ARE IN SERIES. WHAT IS THE TOTAL VALUE? (C = C1×C2 / C1+C2)
A
4,7 nF
B
2,2 nF


IT'LL BE MUCH EASIER TO REMEMBER ALL THIS AFTER WE'VE BUILT A FEW CIRCUITS AND SEEN HOW THEY WORK. BUT FIRST TRANSI WILL HAVE TO EXPLAIN SEMICONDUCTORS.
NOW WHERE IS HE?!
FAST ASLEEP, I SUPPOSE...
IT'S HIGH TIME HE DID SOMETHING USEFUL - AH, THERE HE IS...
WE'LL SEE ABOUT THAT!
BOOH!
HURRAH!
IT'S YOUR TURN NOW! GET CRACKING!
AND DON'T LET ME CATCH YOU READING THAT!
GET A MOVE ON!
... HE FRIGHTENED THE LIFE OUT OF ME!
THERE WAS NO NEED TO SHOUT LIKE THAT!
WHERE DO I START?
WHAT CAN I TELL THEM ABOUT SEMICONDUCTORS?
LET'S SEE..
THEY'RE MADE OF SILICON...
YES! THAT'S AS GOOD A PLACE TO START AS ANY. MOST SEMICONDUCTORS ARE MADE OF SILICON, NOWADAYS - TRANSISTORS ANYWAY.
SILICON IS A VERY BAD CONDUCTOR. ITS ATOMS BUILD UP A VERY TIGHT STRUCTURE, WITH ALL THE ELECTRONS LOCKED TIGHTLY IN PLACE. IT'S ALMOST AN INSULATOR!
TINY TRACES OF OTHER MATERIAL WILL LOOSEN THIS STRUCTURE, MAKING IT JUST POSSIBLE FOR THE ELECTRONS TO SQUIRM THROUCH. THIS IS WHAT WE CALL 'SEMICONDUCTING' MATERIAL.
OUR LITTLE GREEN FRIEND WILL TELL YOU WHAT IT'S LIKE INSIDE.
N-TYPE (NEGATIVE) SEMICONDUCTORS ARE LIKE THIS. EACH SILICON (SI) ATOM HAS FOUR OUTER ELECTRONS. WHEN WE ADD SOME PHOSPHOR (P), WHICH HAS FIVE, IT COPIES THE SILICON: IT KEEPS FOUR ELECTRONS RUNNING ROUND IT, AND LEAVES THE FIFTH FREE TO ROAM AROUND. THIS LITTLE FELLOW CAN JOIN IN A CURRENT FLOW.
SI
P
NO ROOM!
SO MUCH FOR THE 'NEGATIVE' (N-TYPE) OF MATERIAL. THERE IS ALSO A 'POSITIVE' (P-TYPE), WHICH IS SHORT OF ELECTRONS...
THIS IS FUN!
YD

WHEN WE ADD A TINY TRACE OF ALUMINIUM (Al) TO THE SILICON, IT ALSO TRIES TO FIT IN. BUT IT ONLY HAS THREE OUTER ELECTRONS, SO IT'S ONE SHORT. THIS LEAVES A 'HOLE' IN THE MATERIAL!

AN ELECTRON FROM A NEIGHBOURING ATOM CAN JUMP INTO THIS HOLE, BUT THIS LEAVES A NEW HOLE NEAR THE ATOM THAT HE CAME FROM. ANOTHER ELECTRON JUMPS IN THERE, LEAVING ANOTHER HOLE. AND SO ON...

HOP!

FUTURE HOLE | HOLE | HOLE | OLD HOLE

THE DIODE IS THE SIMPLEST SEMICONDUCTOR. HE IS VERY SMALL, AS YOU CAN SEE, AND HE ONLY HAS TWO WIRES.

A = ANODE

C = CATHODE (INDICATED BY LINE)

TO MAKE A DIODE, P TYPE AND N TYPE SEMICONDUCTORS ARE JOINED. THE JUNCTION IS THE HEART OF THE SEMICONDUCTOR DIODE.

HEY, LOOK! LET'S PLAY GOLF!

N-TYPE MATERIAL, WITH FREE ELECTRONS

P-TYPE MATERIAL, WITH HOLES

THE ELECTRONS NEAREST THE JUNCTION JUMP ACROSS TO THE NEARBY HOLES. THIS CAUSES A POSITIVE AND NEGATIVE 'CHARGE' AT THE JUNCTION...

N + − P

FORE!!!

... AND THIS 'POTENTIAL BARRIER' STOPS THE OTHER ELECTRONS IN THE N-TYPE MATERIAL FROM MOVING UP.

AN ELECTRIC CURRENT CAN ONLY PASS THIS BARRIER UNDER TWO CONDITIONS:

1) IT MUST FLOW IN THE RIGHT DIRECTION, FROM A TO C.

2) THE VOLTAGE MUST BE ABOVE A CERTAIN 'THRESHOLD' LEVEL - 0.7 V FOR SILICON SEMICONDUCTORS. (THERE ARE OTHER TYPES!)

0.7 V MINI

THIS P-N-JUNCTION CAN BE COMPARED TO A HATCH.

0.7 V

GRRR..

THE ELECTRONS CAN ONLY PASS THROUGH IN ONE DIRECTION.

YOU CAN USE THE 'CONTINUITY TESTER' TO TRY THIS. WHEN THE LEADS ARE CONNECTED TO A DIODE ONE WAY ROUND, CURRENT WILL FLOW AND...

... THE LED WILL LIGHT. CONNECTED THE OTHER WAY, THE DIODE WILL BLOCK. NO CURRENT: NO LIGHT!

THIS EFFECT CAN BE USED TO CONVERT AN ALTERNATING CURRENT INTO A DIRECT CURRENT. A DIODE AND A CAPACITOR DO THE WHOLE JOB!

YOU SHOW THEM!

+ V − 0V

A SINE-WAVE, IN FACT, MY DEAR WATSON!

THIS IS AN ALTERNATING VOLTAGE.

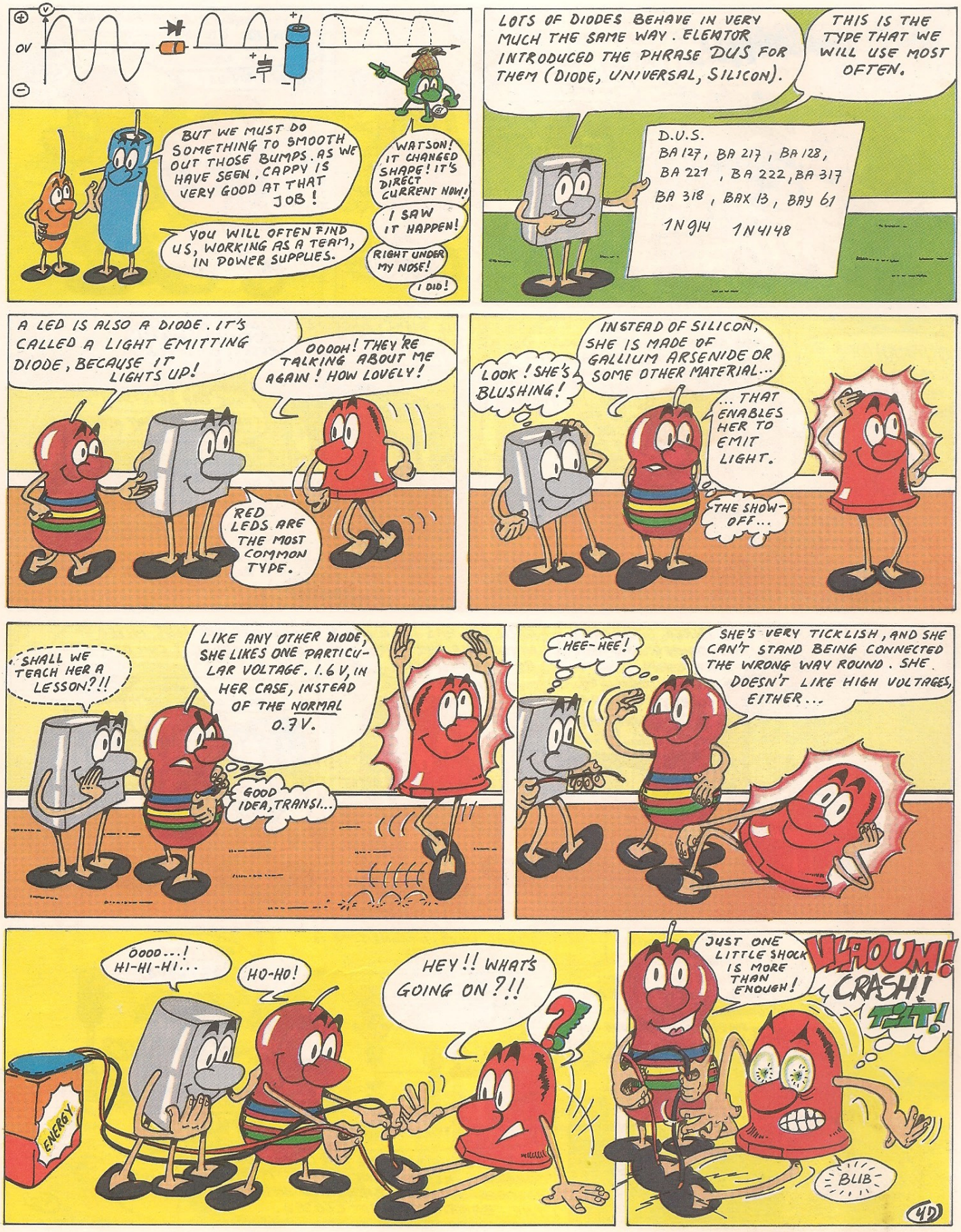
IF IT IS CONNECTED TO A DIODE, CURRENT WILL ONLY FLOW IN ONE DIRECTION - NOT IN THE OTHER.

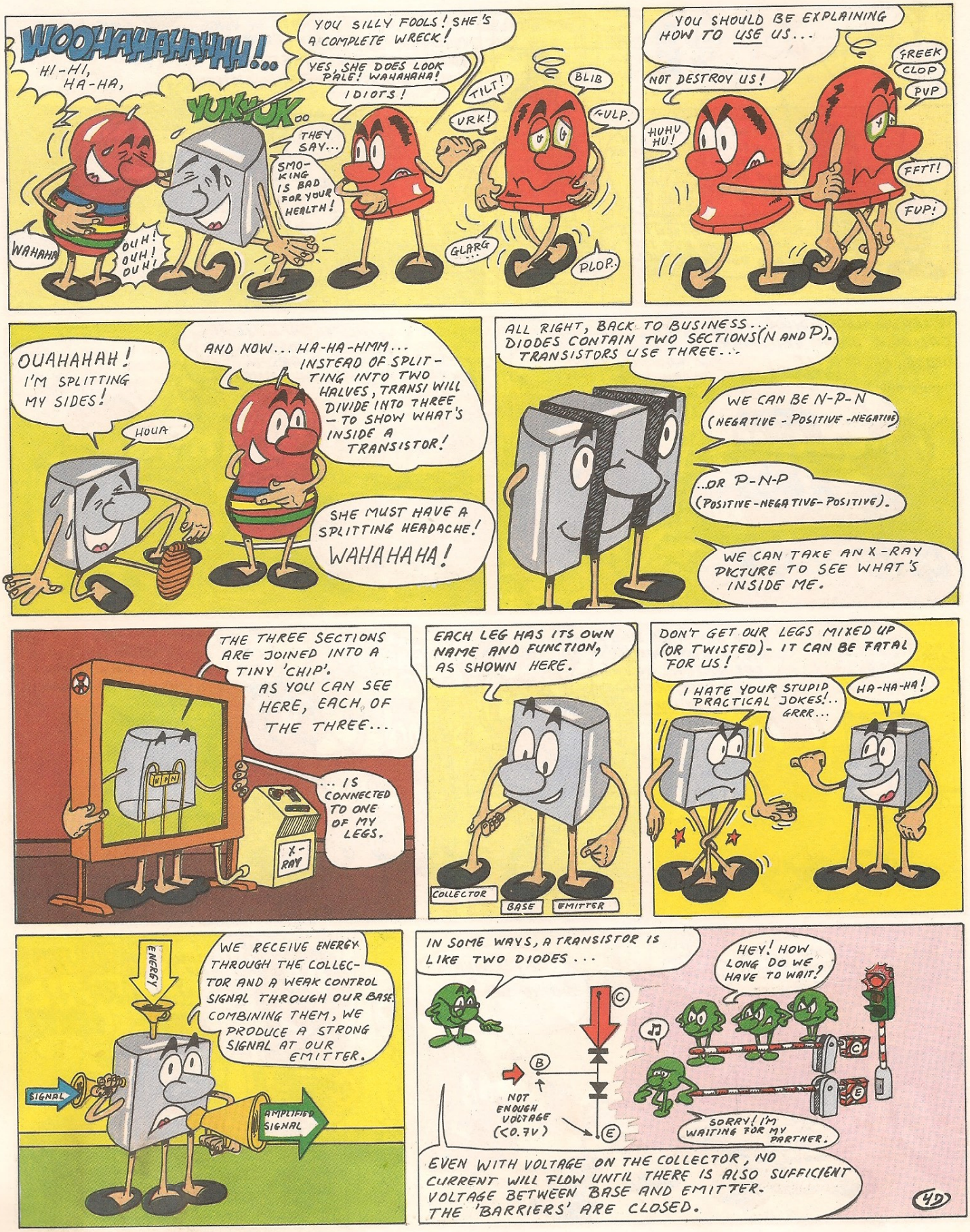
A C

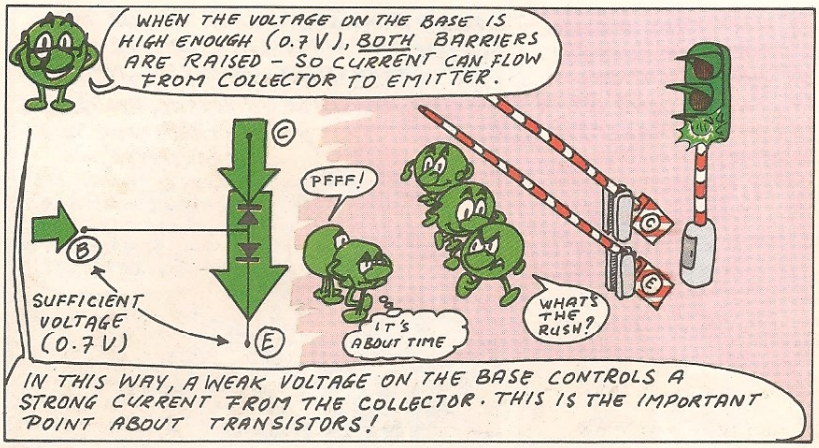
THIS LEAVES US WITH THE POSITIVE HALVES OF THE SINE-WAVE.

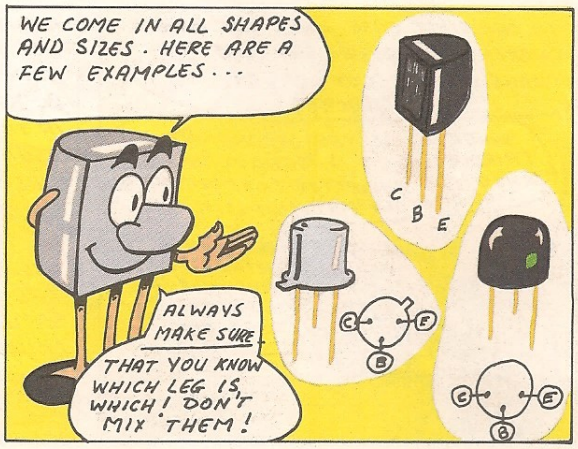
C A

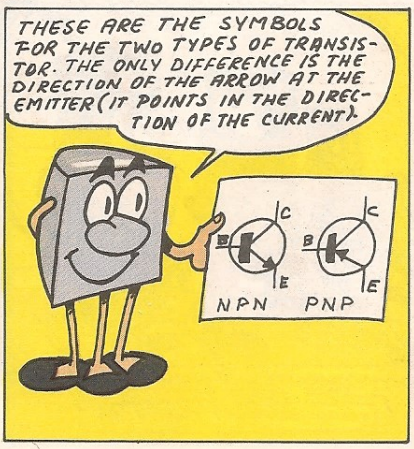
IF YOU TURN ME ROUND, I WILL ONLY PASS THE NEGATIVE HALVES. IT'S AS SIMPLE AS THAT!


0V
BUT WE MUST DO SOMETHING TO SMOOTH OUT THOSE BUMPS. AS WE HAVE SEEN, CAPPY IS VERY GOOD AT THAT JOB!
YOU WILL OFTEN FIND US, WORKING AS A TEAM, IN POWER SUPPLIES.
WATSON! IT CHANGED SHAPE! IT'S DIRECT CURRENT NOW!
I SAW IT HAPPEN!
RIGHT UNDER MY NOSE!
I DID!
LOTS OF DIODES BEHAVE IN VERY MUCH THE SAME WAY. ELEKTOR INTRODUCED THE PHRASE DUS FOR THEM (DIODE, UNIVERSAL, SILICON).
THIS IS THE TYPE THAT WE WILL USE MOST OFTEN.
D.U.S.
BA 127, BA 217, BA 128,
BA 221, BA 222, BA 317
BA 318, BAX 13, BAY 61
1N914 1N4148
A LED IS ALSO A DIODE. IT'S CALLED A LIGHT EMITTING DIODE, BECAUSE IT LIGHTS UP!
OOOOH! THEY'RE TALKING ABOUT ME AGAIN! HOW LOVELY!
RED LEDS ARE THE MOST COMMON TYPE.
LOOK! SHE'S BLUSHING!
INSTEAD OF SILICON, SHE IS MADE OF GALLIUM ARSENIDE OR SOME OTHER MATERIAL...
... THAT ENABLES HER TO EMIT LIGHT.
OH, THE SHOW-OFF...
SHALL WE TEACH HER A LESSON?!!
LIKE ANY OTHER DIODE, SHE LIKES ONE PARTICULAR VOLTAGE. 1.6 V, IN HER CASE, INSTEAD OF THE NORMAL 0.7 V.
GOOD IDEA, TRANSI...
HEE-HEE!
SHE'S VERY TICKLISH, AND SHE CAN'T STAND BEING CONNECTED THE WRONG WAY ROUND. SHE DOESN'T LIKE HIGH VOLTAGES, EITHER...
OOOD...! HI-HI-HI...
HO-HO!
HEY!! WHAT'S GOING ON?!!
ENERGY
JUST ONE LITTLE SHOCK IS MORE THAN ENOUGH!
VLAOUM!
CRASH!
TZIT!
BLIB
4D

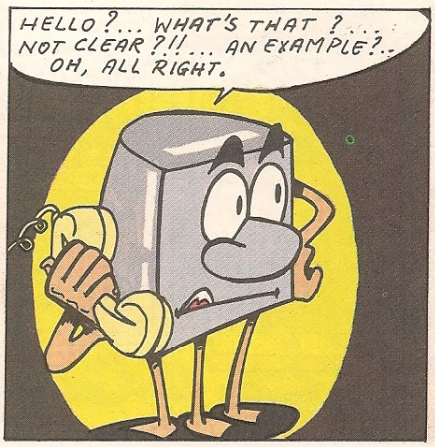

WOOHAHAHAHHH!..
HI-HI, HA-HA,
YUK-YUK
WAHAHA
OUH! OUH! OUH!
THEY SAY... SMOKING IS BAD FOR YOUR HEALTH!
YOU SILLY FOOLS! SHE'S A COMPLETE WRECK!
YES, SHE DOES LOOK PALE! WAHAHAHA!
IDIOTS!
TILT!
VRK!
BLIB
GULP.
GLARG
PLOP.
YOU SHOULD BE EXPLAINING HOW TO USE US...
NOT DESTROY US!
HUHU HU!
FREEK
CLOP
PUP
FFTT!
FUP!
OUAHAHAH! I'M SPLITTING MY SIDES!
HOUA
AND NOW... HA-HA-HMM... INSTEAD OF SPLITTING INTO TWO HALVES, TRANSI WILL DIVIDE INTO THREE - TO SHOW WHAT'S INSIDE A TRANSISTOR!
SHE MUST HAVE A SPLITTING HEADACHE! WAHAHAHA!
ALL RIGHT, BACK TO BUSINESS... DIODES CONTAIN TWO SECTIONS (N AND P). TRANSISTORS USE THREE...
WE CAN BE N-P-N (NEGATIVE - POSITIVE - NEGATIVE)
...OR P-N-P (POSITIVE - NEGATIVE - POSITIVE).
WE CAN TAKE AN X-RAY PICTURE TO SEE WHAT'S INSIDE ME.
THE THREE SECTIONS ARE JOINED INTO A TINY 'CHIP'. AS YOU CAN SEE HERE, EACH OF THE THREE...
... IS CONNECTED TO ONE OF MY LEGS.
X-RAY
EACH LEG HAS ITS OWN NAME AND FUNCTION, AS SHOWN HERE.
COLLECTOR
BASE
EMITTER
DON'T GET OUR LEGS MIXED UP (OR TWISTED) - IT CAN BE FATAL FOR US!
I HATE YOUR STUPID PRACTICAL JOKES!.. GRRR...
HA-HA-HA!
ENERGY
SIGNAL
WE RECEIVE ENERGY THROUGH THE COLLECTOR AND A WEAK CONTROL SIGNAL THROUGH OUR BASE. COMBINING THEM, WE PRODUCE A STRONG SIGNAL AT OUR EMITTER.
AMPLIFIED SIGNAL
IN SOME WAYS, A TRANSISTOR IS LIKE TWO DIODES...
HEY! HOW LONG DO WE HAVE TO WAIT?
C
B
E
NOT ENOUGH VOLTAGE (<0.7V)
SORRY! I'M WAITING FOR MY PARTNER.
EVEN WITH VOLTAGE ON THE COLLECTOR, NO CURRENT WILL FLOW UNTIL THERE IS ALSO SUFFICIENT VOLTAGE BETWEEN BASE AND EMITTER. THE 'BARRIERS' ARE CLOSED.
YD


WHEN THE VOLTAGE ON THE BASE IS HIGH ENOUGH (0.7 V), BOTH BARRIERS ARE RAISED – SO CURRENT CAN FLOW FROM COLLECTOR TO EMITTER.
C
B
E
SUFFICIENT VOLTAGE (0.7 V)
PFFF!
IT'S ABOUT TIME
WHAT'S THE RUSH?
IN THIS WAY, A WEAK VOLTAGE ON THE BASE CONTROLS A STRONG CURRENT FROM THE COLLECTOR. THIS IS THE IMPORTANT POINT ABOUT TRANSISTORS!

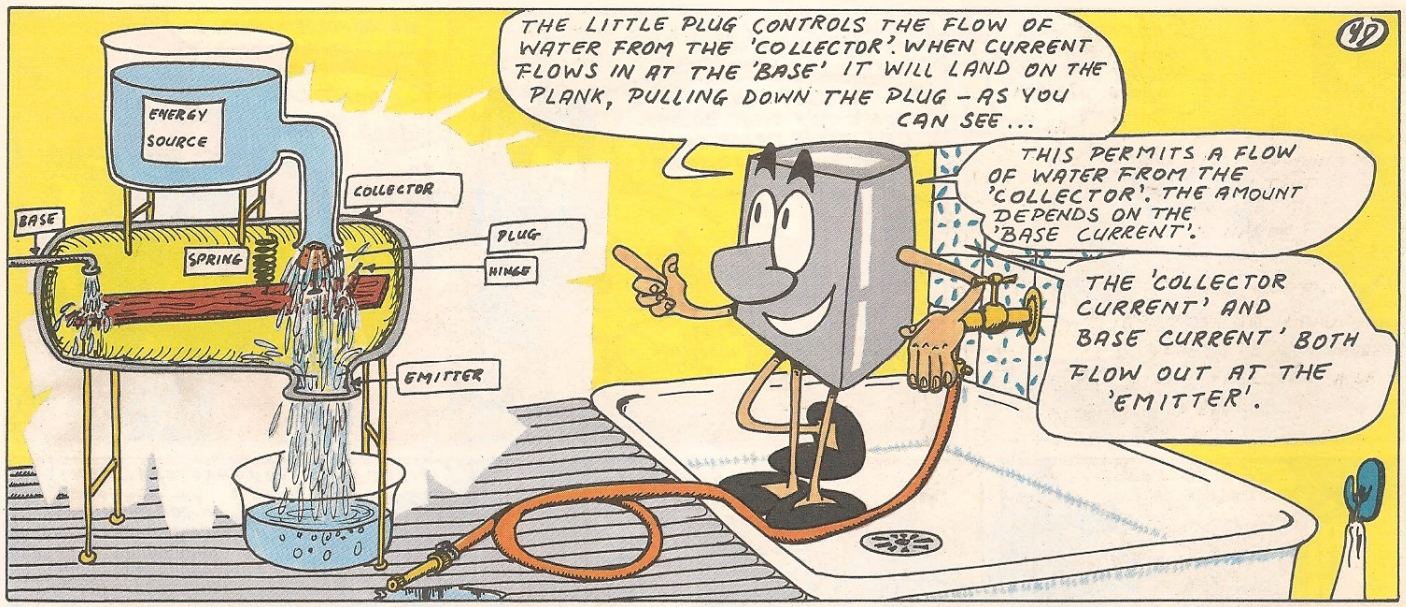

WE COME IN ALL SHAPES AND SIZES. HERE ARE A FEW EXAMPLES...
C B E
C E B
E E B
ALWAYS MAKE SURE
THAT YOU KNOW WHICH LEG IS, WHICH! DON'T MIX THEM!

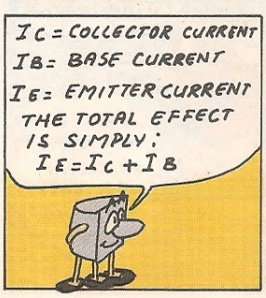

THESE ARE THE SYMBOLS FOR THE TWO TYPES OF TRANSISTOR. THE ONLY DIFFERENCE IS THE DIRECTION OF THE ARROW AT THE EMITTER (IT POINTS IN THE DIRECTION OF THE CURRENT).
B C E
NPN
PNP

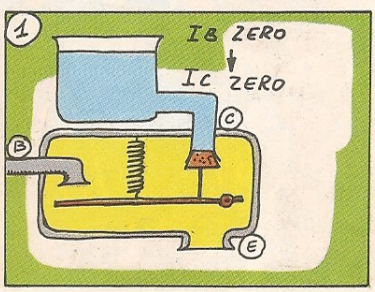

DRRRRRRG!
?

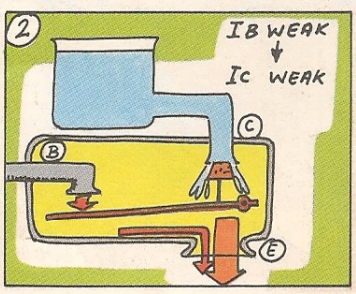

HELLO?... WHAT'S THAT?... NOT CLEAR?!!... AN EXAMPLE?.. OH, ALL RIGHT.

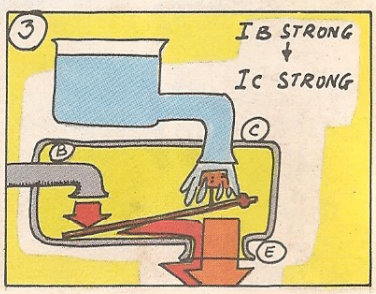

THAT WAS RESI. HE SAYS I SHOULD DEMONSTRATE THE PRINCIPLE. HE SUGGESTS USING WATER...
THIS COULD GET MESSY...
DRIP


4D
THE LITTLE PLUG CONTROLS THE FLOW OF WATER FROM THE 'COLLECTOR'. WHEN CURRENT FLOWS IN AT THE 'BASE' IT WILL LAND ON THE PLANK, PULLING DOWN THE PLUG – AS YOU CAN SEE...
THIS PERMITS A FLOW OF WATER FROM THE 'COLLECTOR'. THE AMOUNT DEPENDS ON THE 'BASE CURRENT'.
THE 'COLLECTOR CURRENT' AND BASE CURRENT' BOTH FLOW OUT AT THE 'EMITTER'.
ENERGY SOURCE
COLLECTOR
BASE
SPRING
PLUG
HINGE
EMITTER


IC = COLLECTOR CURRENT
IB = BASE CURRENT
IE = EMITTER CURRENT
THE TOTAL EFFECT IS SIMPLY:
IE = IC + IB


1
IB ZERO
IC ZERO
C
B
E


2
IB WEAK
IC WEAK
C
B
E


3
IB STRONG
IC STRONG
C
B
E

IN THE FIRST CASE, WHEN THE BASE CURRENT IS ZERO, WE SAY THAT THE TRANSISTOR IS 'CUT OFF', OR 'BLOCKED'...

WHEREAS IN THE SECOND AND THIRD CASES IT IS 'CONDUCTING'. WHEN THE COLLECTOR CURRENT REACHES A CERTAIN MAXIMUM LEVEL...

IT WILL NOT INCREASE ANY FURTHER. THE TRANSISTOR IS 'IN SATURATION'.

ANOTHER WORD THAT WE WILL USE IS 'GAIN'. THE 'CURRENT GAIN' OR AMPLIFICATION (B, 'BETA', THE SECOND LETTER IN THE GREEK ALPHABET) IS USUALLY MORE THAN 100. THIS SIMPLY MEANS THAT THE COLLECTOR CURRENT WILL BE 100 TIMES GREATER THAN THE BASE CURRENT — UNTIL THE TRANSISTOR SATURATES, OF COURSE.

$I_C = \beta \times I_B$

THE TRANSISTORS THAT WE USE MOST OFTEN ARE WHAT ELEKTOR HAS CALLED TUN (TRANSISTOR, UNIVERSAL, NPN) AND TUP (TRANSISTOR UNIVERSAL, PNP). THIS STANDS FOR 'ANY TRANSISTOR, NO MATTER WHAT ITS OFFICIAL NUMBER IS, THAT MEETS A FEW SIMPLE REQUIREMENTS'.

HERE IS A LIST OF SOME OF THE MOST COMMON TYPES...

... BUT THERE ARE LOTS AND LOTS MORE!

TUN (NPN)	TUP (PNP)
Bc 107	Bc 177
Bc 108	Bc 178
Bc 109	Bc 179
Bc 147 (148-149)	Bc 157 (-8-9)
Bc 207 (-8-9)	Bc 204 (-5-6)
Bc 237 (-8-9)	Bc 307 (-8-9)
Bc 317 (-8-9)	Bc 320 (-1-2)
Bc 347 (-8-9)	Bc 350 (-1-2)
ETC.	ETC.

LATER ON, YOU WILL DISCOVER THAT I HAVE A GREAT MANY RELATIVES. THERE ARE FIELD-EFFECT TRANSISTORS (FETS), UNIJUNCTION TRANSISTORS (UJTS), PHOTO-TRANSISTORS, AND A WHOLE RANGE OF POWER TRANSISTORS (THOSE ARE MY BIG BROTHERS!).

TRANSISTOR FAMILY PORTRAIT

OOFFF! JOB DONE! THAT WASN'T TOO BAD, AFTER ALL!

PFFF!

HEY! WHERE DO YOU THINK YOU'RE GOING?

TO BED! AND DON'T TRY THAT BUCKET-OF-WATER TRICK AGAIN, OR ELSE!

I'M WARNING YOU!

WE'RE NOT FINISHED!

I DON'T CARE!! GOOD NIGHT!

SLAM!

KLIK

HE'S LOCKED HIMSELF IN!

THE BLIGHTER!

?

ZZZ

OK! I'LL GIVE YOU HALF AN HOUR! BUT WE'VE STILL GOT A LOT TO DO!

LAZYBONES...

HiHiHi!

RIGHT! RESI, YOU TAKE OVER FROM HERE!

ME? WHY ME? YOU'RE NOT DOING ANYTHING!

YES I AM! I'M CO-ORDINATING!

GOLLY! HE SEEMS TO THINK HE'S THE BIG BOSS!

YD

TRANS! FORGOT TO MENTION THAT THERE ARE OTHER 'ACTIVE' COMPONENTS, BESIDES TRANSISTORS. FOR INSTANCE, THERE'S GRANDPA VALVE - THE AMERICANS CALL HIM 'TUBE'.

TUBE!!! WATCH YOUR LANGUAGE, YOUNG MAN.

HE ISN'T USED VERY OFTEN NOWADAYS, BUT YOU CAN STILL FIND HIM IN TV SETS, RADAR, AND OTHER ODD PLACES LIKE THAT.

AHHH... THOSE WERE THE DAYS..!

THEN THERE ARE DIACS, TRIACS,...

... AND THYRISTORS. THEY OFTEN LOOK JUST LIKE TRANSISTORS!

WE DO VERY SPECIAL JOBS!

DIAC

A1 G A2 TRIAC

G A K THYRISTOR

LAST BUT NOT LEAST: THE INTEGRATED CIRCUIT (IC).

HE'S LIKE A PLASTIC CATERPILLAR!

I DON'T BELONG IN THIS BOOK, BUT WE'RE SURE TO MEET AGAIN IN THE FUTURE!

NOW, LET'S GET THINGS MOVING...

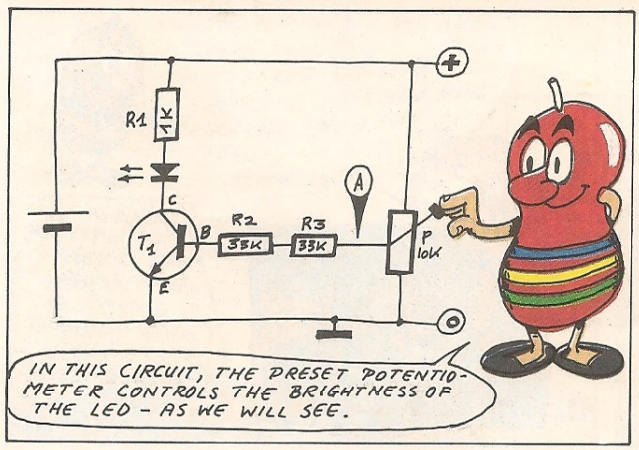
WE'RE GOING TO START BUILDING A FEW INTERESTING CIRCUITS NOW. ALONG THE WAY, WE WILL...

... ALSO DO A FEW SUMS. THEY'RE NOT HARD, AND THEY DO HELP YOU TO UNDERSTAND WHAT'S HAPPENING IN ELECTRONIC CIRCUITS...

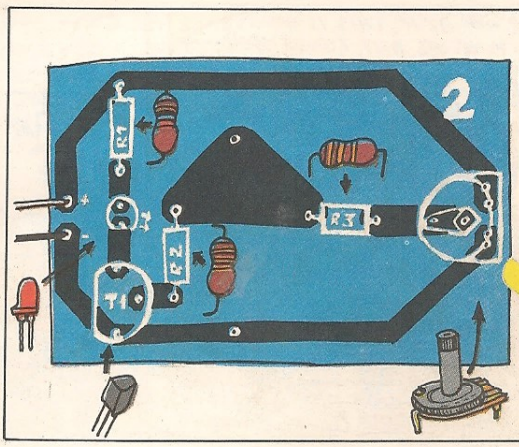
LET'S START ON CIRCUIT 2. FOR THIS, WE NEED:

A BATTERY CONNECTOR, A 1K RESISTOR, A LED, A TUN, TWO 33K RESISTORS A 100µF/10V CAPACITOR, AND A 10K PRESET POTENTIOMETER.

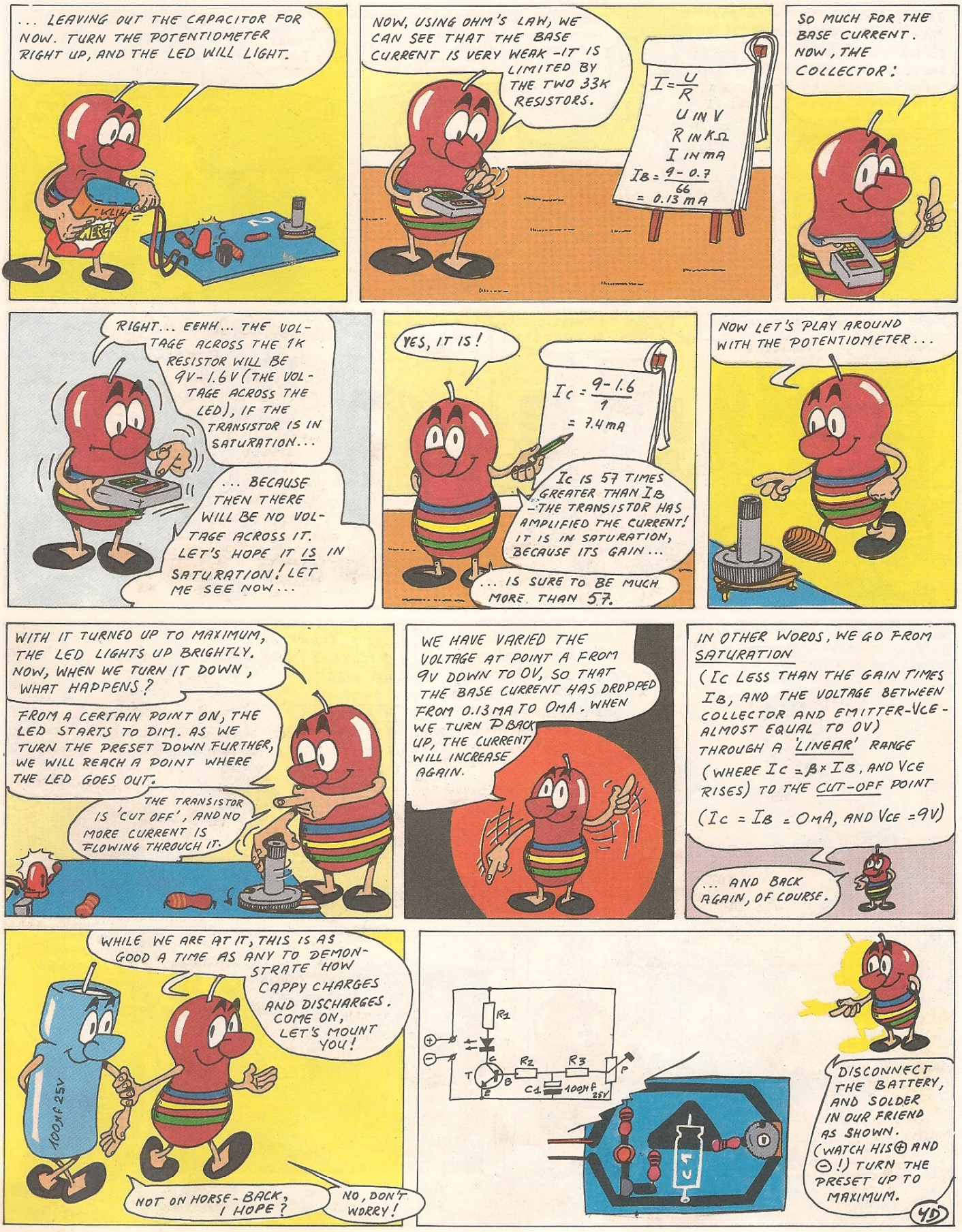
NOTE THAT '100µF/10V' MEANS THAT THE VOLTAGE RATING OF THE ELCO MUST BE AT LEAST 10V. 16V OR 25V WILL ALSO DO!



IN THIS CIRCUIT, THE PRESET POTENTIOMETER CONTROLS THE BRIGHTNESS OF THE LED - AS WE WILL SEE.



FIRST WE MUST BUILD IT, THOUGH. MOUNT THE COMPONENTS LIKE THIS...

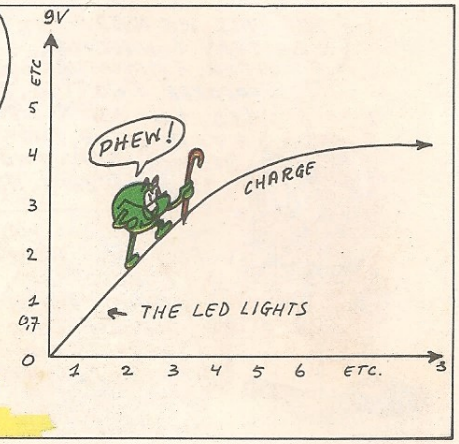

... LEAVING OUT THE CAPACITOR FOR NOW. TURN THE POTENTIOMETER RIGHT UP, AND THE LED WILL LIGHT.
NOW, USING OHM'S LAW, WE CAN SEE THAT THE BASE CURRENT IS VERY WEAK -IT IS LIMITED BY THE TWO 33K RESISTORS.
I = U/R
U IN V
R IN K.Ω
I IN MA
IB = 9 - 0.7 / 66 = 0.13 MA
SO MUCH FOR THE BASE CURRENT. NOW, THE COLLECTOR:
RIGHT... EEHH... THE VOLTAGE ACROSS THE 1K RESISTOR WILL BE 9V - 1.6V (THE VOLTAGE ACROSS THE LED), IF THE TRANSISTOR IS IN SATURATION...
... BECAUSE THEN THERE WILL BE NO VOLTAGE ACROSS IT. LET'S HOPE IT IS IN SATURATION! LET ME SEE NOW...
YES, IT IS!
IC = 9 - 1.6 / 1 = 7.4 MA
IC IS 57 TIMES GREATER THAN IB -THE TRANSISTOR HAS AMPLIFIED THE CURRENT! IT IS IN SATURATION, BECAUSE ITS GAIN ...
... IS SURE TO BE MUCH MORE THAN 57.
NOW LET'S PLAY AROUND WITH THE POTENTIOMETER...
WITH IT TURNED UP TO MAXIMUM, THE LED LIGHTS UP BRIGHTLY. NOW, WHEN WE TURN IT DOWN, WHAT HAPPENS?
FROM A CERTAIN POINT ON, THE LED STARTS TO DIM. AS WE TURN THE PRESET DOWN FURTHER, WE WILL REACH A POINT WHERE THE LED GOES OUT.
THE TRANSISTOR IS 'CUT OFF', AND NO MORE CURRENT IS FLOWING THROUCH IT.
WE HAVE VARIED THE VOLTAGE AT POINT A FROM 9V DOWN TO 0V, SO THAT THE BASE CURRENT HAS DROPPED FROM 0.13 MA TO 0MA. WHEN WE TURN P BACK UP, THE CURRENT WILL INCREASE AGAIN.
IN OTHER WORDS, WE GO FROM SATURATION (IC LESS THAN THE GAIN TIMES IB, AND THE VOLTAGE BETWEEN COLLECTOR AND EMITTER -VCE - ALMOST EQUAL TO 0V) THROUGH A 'LINEAR' RANGE (WHERE IC = β × IB, AND VCE RISES) TO THE CUT-OFF POINT (IC = IB = 0MA, AND VCE = 9V)
... AND BACK AGAIN, OF COURSE.
WHILE WE ARE AT IT, THIS IS AS GOOD A TIME AS ANY TO DEMONSTRATE HOW CAPPY CHARGES AND DISCHARGES. COME ON, LET'S MOUNT YOU!
100MF 25V
NOT ON HORSE-BACK, I HOPE?
NO, DON'T WORRY!
R1
R2
R3
P
T
C
B
E
C1
100MF 25V
DISCONNECT THE BATTERY, AND SOLDER IN OUR FRIEND AS SHOWN. (WATCH HIS ⊕ AND ⊖!) TURN THE PRESET UP TO MAXIMUM.
YD

RE-CONNECT THE BATTERY. DID YOU NOTICE ANYTHING? RIGHT! IT TOOK A LITTLE WHILE FOR THE LED TO LIGHT!

IT HAD TO 'WAIT' UNTIL THE CAPACITOR HAD CHARGED SUFFICIENTLY TO 'TURN ON' THE TRANSISTOR.

EVEN WHEN THE LED LIGHTS, THE CAPACITOR IS STILL CHARGING. IT TAKES ABOUT 15 SECONDS FOR IT TO CHARGE RIGHT UP IN THIS CASE.

AS YOU CAN SEE HERE, THE LED LIGHTS AT QUITE AN EARLY POINT IN THE 'CHARGING CURVE'



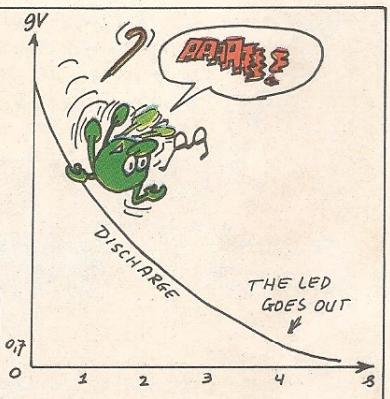
WAIT ABOUT FIFTEEN SECONDS, THEN RAPIDLY TURN THE POTENTIOMETER RIGHT DOWN.

ZOT!

NOTHING WILL HAPPEN FOR A SHORT TIME - THEN THE LED WILL GO OUT.

IT WON'T GO OUT COMPLETELY UNTIL THE VOLTAGE HAS DROPPED BELOW THE 'THRESHOLD' OF THE TRANSISTOR (0.7 V).

DON'T WORRY IF IT TAKES MORE OR LESS TIME THAN WE SHOW HERE - THESE DRAWINGS ARE JUST A SKETCH, TO SHOW THE PRINCIPLE.



I CHOSE A 100 µF CAPACITOR. IF I HAD USED 1 µF OR 100 nF, IT WOULD ALL HAVE HAPPENED TOO QUICKLY FOR YOU TO SEE...

... AND IF I USED 10000 µF, YOU WOULD HAVE HAD TIME FOR A WALK ROUND THE BLOCK!

FAVOURITISM!

LET'S TRY SOMETHING ELSE. BEFORE WE ADDED CAPPY, YOU SAW HOW THE BRIGHTNESS OF THE LED VARIED AS YOU TURNED THE POTENTIOMETER TO AND FRO. NOW, HOWEVER, ...

... IF YOU TWIST IT RAPIDLY TO AND FRO YOU WILL FIND THAT THE BRIGHTNESS OF THE LED DOESN'T CHANGE. THE CAPACITOR IS 'SMOOTHING' THE VARYING VOLTAGE FROM THE POTENTIOMETER.

ONLY WHEN YOU TURN IT VERY SLOWLY, THE BRIGHTNESS OF THE LED WILL FOLLOW STEP.

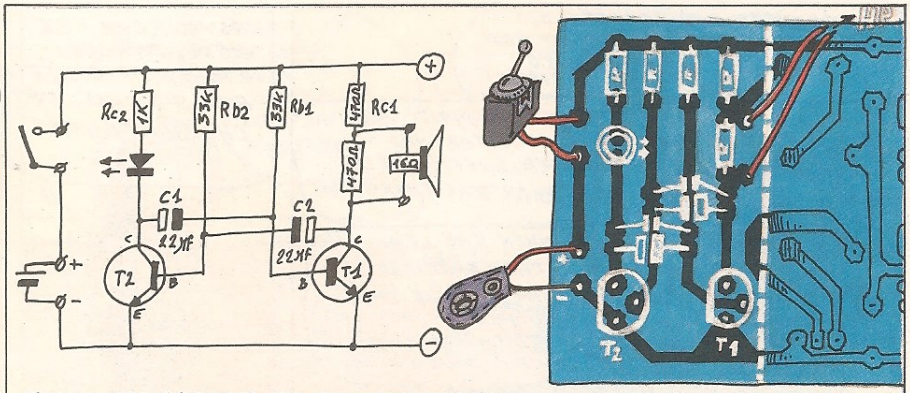
NOW, LET'S TRY SOMETHING COMPLETELY DIFFERENT. WE WILL USE THE TRANSISTOR AS A 'SWITCH' IN THIS NEXT CIRCUIT: IT WILL BE 'ALL OR NOTHING,' AS FAR AS THE CURRENT IS CONCERNED!

THIS CIRCUIT OCCUPIES PART OF SECTION 3 OF THE PRINTED CIRCUIT BOARD. IT IS A 'SQUARE-WAVE GENERATOR', THAT CAN BE USED FOR FLASHING LIGHTS OR AS A SIREN.

FOR THIS, WE NEED: A BATTERY CONNECTOR, A SWITCH, A MINIATURE LOUDSPEAKER, TWO TUNS, A LED, TWO 33K RESISTORS, A 1K RESISTOR, TWO 470Ω RESISTORS AND TWO 22µF/10V CAPACITORS.

LIST

BY THE WAY: DON'T WORRY ABOUT THE EXACT 'VALUE' FOR THE LOUDSPEAKER - ANYTHING BETWEEN 8Ω AN 35Ω WILL DO!



TWO WIRES ARE USED TO CONNECT THE LOUDSPEAKER TO THE BOARD. THE REST OF THE BOARD WILL BE USED LATER ON!

JUST FOR THIS ONCE. YOU SHOULD MOUNT THE TWO CAPACITORS 'IN MIDAIR'. IN OTHER WORDS: DON'T SHORTEN THE WIRES AT ALL!

22µF 25V

LATER ON, WE WILL REMOVE THEM AGAIN BY CUTTING THEIR LEADS OFF AT THE BOARD. THAT WAY, THERE'S NO NEED TO UNSOLDER THEM (IT SAVES DAMAGING THE BOARD, OR BURNING YOUR FINGERS!)...

... AND WE CAN RE-USE THEM ELSEWHERE.

THESE FOUR HOLES ARE NOT USED YET.

THE TWO TRANSISTORS WILL CONDUCT AND BLOCK, ALTERNATELY. WHEN ONE IS 'ON', THE OTHER IS 'OFF' THIS WILL CAUSE THE LED TO FLASH.

SINCE THE TWO 'BASE RESISTORS' (RB1 AND RB2) ARE BOTH THE SAME VALUE, AND THE SAME APPLIES TO C1 AND C2, THE TRANSISTORS WILL SWITCH TO AND FRO AT REGULAR INTERVALS.

THE 'ON' TIME AND 'OFF' TIME OF THE LED ARE THE SAME.

TOC TOC

IF YOU LIKE, YOU CAN PLAY AROUND WITH SOME OTHER VALUES. FOR INSTANCE, CONNECT A 4K7 RESISTOR IN PARALLEL WITH RB1 OR RB2. OR CONNECT A 100µF CAPACITOR ACROSS C1 OR C2. DON'T WORRY, YOU WON'T DAMAGE ANYTHING! MEANWHILE, THE LOUDSPEAKER WILL BE TICKING AWAY...

... OR MAYBE IT'S MORE LIKE TOCK!

TOC

TO GET AN IDEA HOW THE CIRCUIT WORKS, LET'S FIRST ASSUME THAT T1 IS CONDUCTING. C2 WILL CHARGE THROUGH RB2, SO THE VOLTAGE AT THE BASE OF T2 WILL SLOWLY RISE. WHEN IT REACHES THE THRESHOLD VOLTAGE OF T2 (0.7V), THIS TRANSISTOR WILL TURN ON - IT IS AS IF A PIECE OF WIRE IS CONNECTED SUDDENLY BETWEEN ITS COLLECTOR AND EMITTER! THE LED WILL LIGHT. AT THE SAME TIME...

TOCK!

GOOD ONE!

... C1 PULLS THE BASE VOLTAGE OF T1 DOWN, SO THIS TRANSISTOR CUTS OFF. NOW IT'S THIS CAPACITOR'S TURN TO CHARGE, THROUGH RB1, UNTIL THE VOLTAGE AT THE BASE OF T1 AGAIN RISES ABOVE 0.7V. THIS TRANSISTOR TURNS ON AGAIN, TURNING OFF T2, AND THE LOUDSPEAKER GOES 'TOCK!'.

WHAT A SMASH!

AND SO ON...

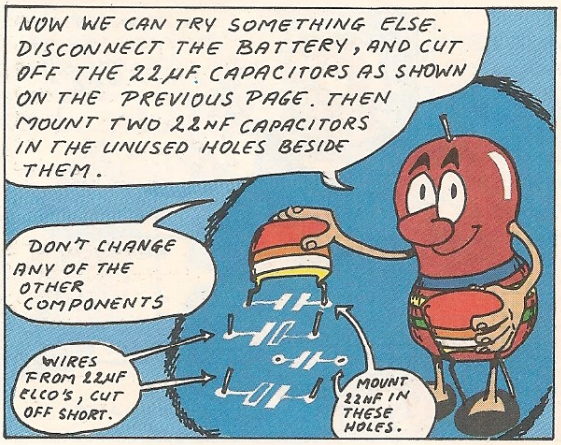
...AND ON...

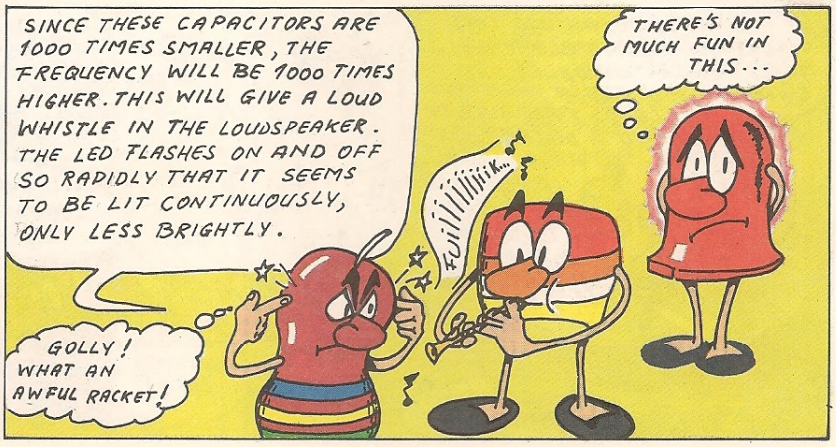
SLURPP!

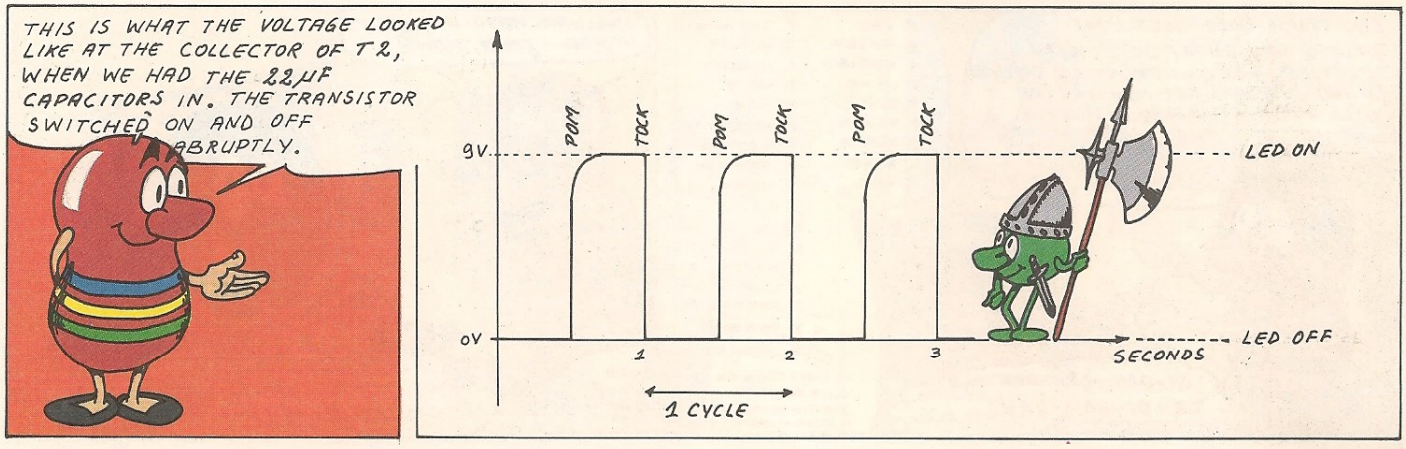
4D

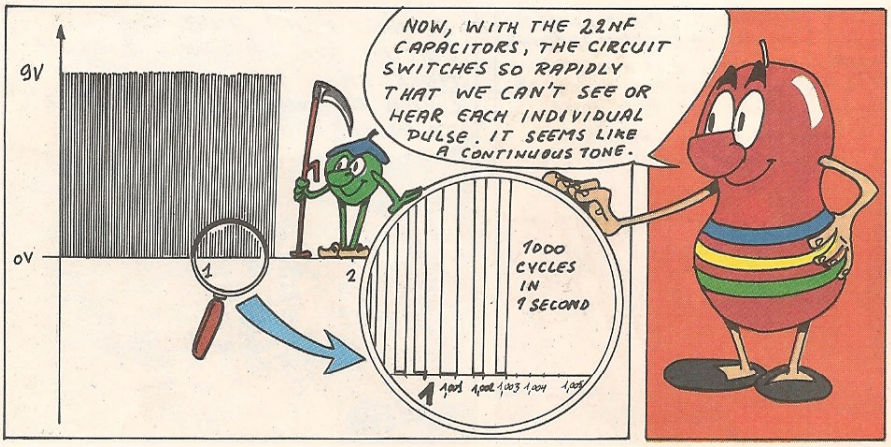

OUCH!
THE VALUES OF C1, C2, RB1 AND RB2 DETERMINE THE FREQUENCY - THAT IS, THE RATE AT WHICH THINGS SWING TO AND FRO.
TOO QUICK FOR ME...

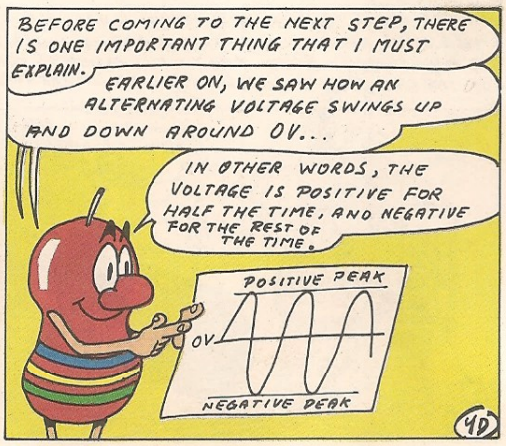

I THINK HE DID THAT ON PURPOSE!
WITH THE 22μF CAPACITORS, THE FREQUENCY IS VERY LOW. YOU CAN SEE THE LED FLASHING ON AND OFF...
... AND YOU CAN HEAR THE LOUDSPEAKER GOING 'TICK-TOCK' AS THE CURRENT THROUGH IT IS SWITCHED ON AND OFF.
POM POH POM


NOW WE CAN TRY SOMETHING ELSE. DISCONNECT THE BATTERY, AND CUT OFF THE 22μF CAPACITORS AS SHOWN ON THE PREVIOUS PAGE. THEN MOUNT TWO 22nF CAPACITORS IN THE UNUSED HOLES BESIDE THEM.
DON'T CHANGE ANY OF THE OTHER COMPONENTS
WIRES FROM 22μF ELCO'S, CUT OFF SHORT.
MOUNT 22nF IN THESE HOLES.


SINCE THESE CAPACITORS ARE 1000 TIMES SMALLER, THE FREQUENCY WILL BE 1000 TIMES HIGHER. THIS WILL GIVE A LOUD WHISTLE IN THE LOUDSPEAKER. THE LED FLASHES ON AND OFF SO RAPIDLY THAT IT SEEMS TO BE LIT CONTINUOUSLY, ONLY LESS BRIGHTLY.
THERE'S NOT MUCH FUN IN THIS...
GOLLY! WHAT AN AWFUL RACKET!

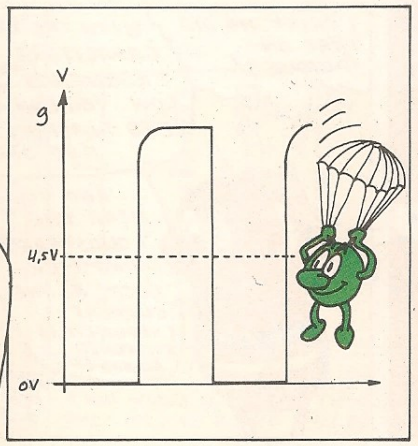

THIS IS WHAT THE VOLTAGE LOOKED LIKE AT THE COLLECTOR OF T2, WHEN WE HAD THE 22μF CAPACITORS IN. THE TRANSISTOR SWITCHED ON AND OFF ABRUPTLY.
9V
0V
POM
TOCK
POM
TOCK
POM
TOCK
LED ON
LED OFF
1
2
3
SECONDS
1 CYCLE


9V
0V
1
2
NOW, WITH THE 22nF CAPACITORS, THE CIRCUIT SWITCHES SO RAPIDLY THAT WE CAN'T SEE OR HEAR EACH INDIVIDUAL PULSE. IT SEEMS LIKE A CONTINUOUS TONE.
1000 CYCLES IN 1 SECOND
1
1,001
1,002
1,003
1,004
1,005


BEFORE COMING TO THE NEXT STEP, THERE IS ONE IMPORTANT THING THAT I MUST EXPLAIN.
EARLIER ON, WE SAW HOW AN ALTERNATING VOLTAGE SWINGS UP AND DOWN AROUND 0V...
IN OTHER WORDS, THE VOLTAGE IS POSITIVE FOR HALF THE TIME, AND NEGATIVE FOR THE REST OF THE TIME.
POSITIVE PEAK
0V
NEGATIVE PEAK
4D

HOWEVER, THE CENTRE LINE FOR OUR SIREN TONE IS NOT OV. IT IS MIDWAY BETWEEN OV AND 9V: 4.5V! THE SIGNAL SWINGS UP AND DOWN AROUND THIS VALUE.

THE 'POSITIVE PEAKS' ARE AT 9V, AND THE 'NEGATIVE PEAKS' ARE ACTUALLY OV - NOT NEGATIVE AT ALL!



IN OTHER WORDS, IT IS AS IF OUR SIGNAL IS A MIXTURE OF TWO VOLTAGES: AN ALTERNATING VOLTAGE OF 9V PEAK-TO-PEAK...

... AND A DIRECT VOLTAGE OF 4.5V. IF NECESSARY, THE DIRECT VOLTAGE CAN BE STOPPED BY A CAPACITOR, AS WE WILL SEE.

BY THE WAY, YOU CAN USE THIS CIRCUIT AS AN AUDIBLE 'CONTINUITY TESTER'. UNSOLDER THE SWITCH, AND TOUCH THE TWO LEADS TO A BULB OR TO A DIODE (BOTH WAYS ROUND). IF YOU HEAR A TONE, THE BULB IS OK - OR THE DIODE IS CONDUCTING.

SWITCH REMOVED

THE TWO LEADS TO THE SWITCH ARE NOW USED AS TEST LEADS. IF YOU DON'T HEAR A TONE...

9V

ETC

... TOUCH THE LEADS TOGETHER TO MAKE SURE YOUR CIRCUIT IS WORKING...

... BEFORE THROWING AWAY THE BULB!

YOU CAN ALSO USE THE CIRCUIT FOR SENDING MORSE CODE. YOU CAN MAKE A 'KEY' WITH A PIECE OF SPRINGY COPPER (OR BUY ONE...).

SPRINGY COPPER

THE MORSE CODE USES LONG DASHES AND SHORT DOTS, WITH PRACTICE, YOU CAN TRANSMIT BETWEEN 20 AND 40 WORDS PER MINUTE. YOU WILL HEAR IT BEING USED ON THE SHORT WAVES.

A ·-
B -···
C -·-·
D -··
E ·
F ··-·
G --·
H ····
I ··
J ·---
K -·-
L ·-··
M --
N -·
O ---
P ·--·
Q --·-
R ·-·
S ···
T -
U ··-
V ···-
W ·--
X -··-
Y -·--
Z --··

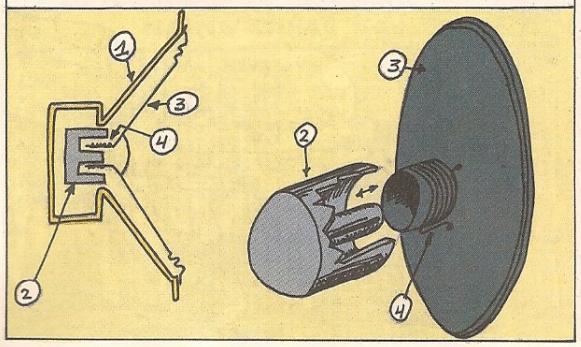
1 ·----
2 ··---
3 ···--
4 ····-
5 ·····
6 -····
7 --···
8 ---··
9 ----·
0 -----

DI-DAH-DAH DAH-DAH DA DI-DAH-DAH!

SHALL WE HAVE A LOOK INSIDE HIM, NOW?

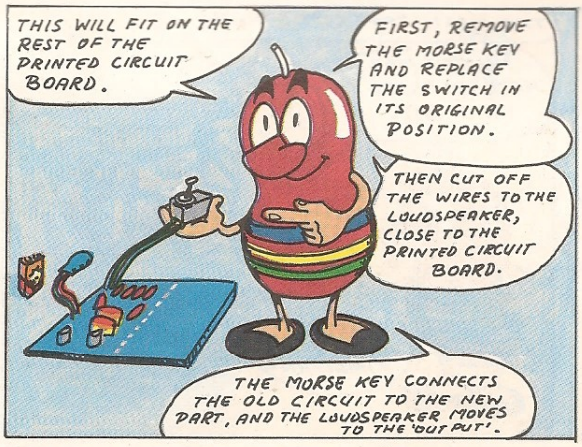
··//-·-·/·-/-·/-·//-/·-/·-···/·-·-//
·-/-·/·-·-//-···/·-/-·/-··/-·/--·/·//
·/···-/·/-·//--/---/·-·/···/·//

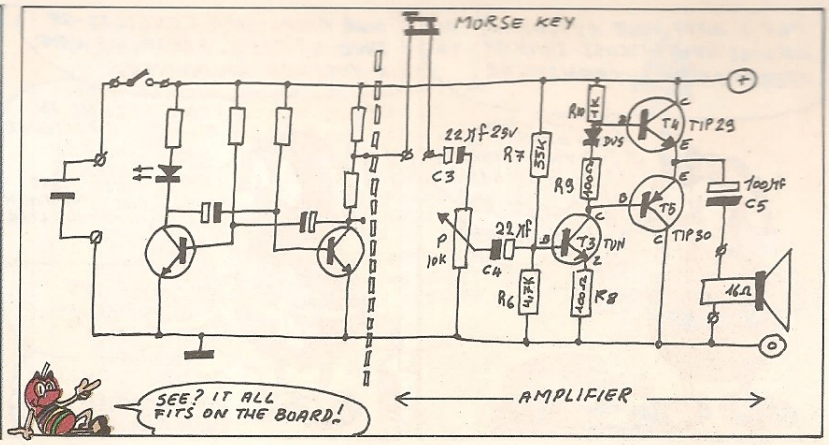
A LOUDSPEAKER CONSISTS OF A METAL 'CHASSIS' (1), A MAGNET (2), A PAPER 'CONE' (3), AND A 'VOICE COIL' (4) THAT IS MOUNTED ON A TUBE. THE TUBE IS GLUED TO THE CENTRE OF THE CONE, AND IT SLIDES TO AND FRO IN THE MAGNET.

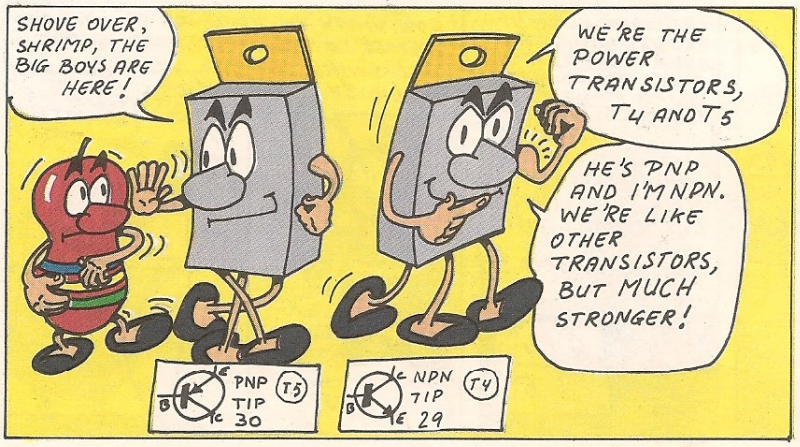


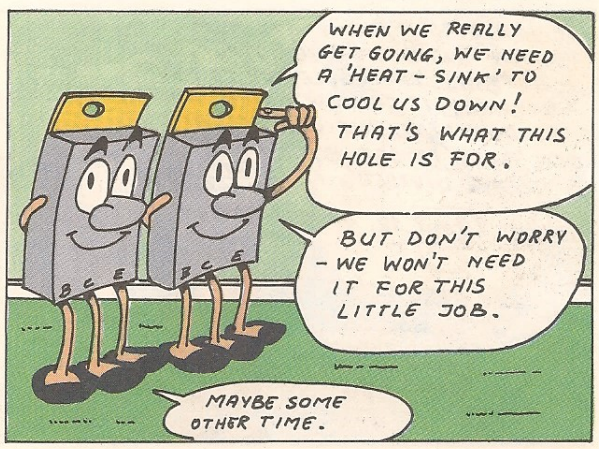
DEPENDING ON THE DIRECTION OF THE CURRENT THROUGH THE COIL, IT IS EITHER SUCKED INTO THE MAGNET OR PUSHED OUT. THIS MOVES THE CONE, CAUSING VIBRATIONS IN THE AIR - WHICH WE CAN HEAR.

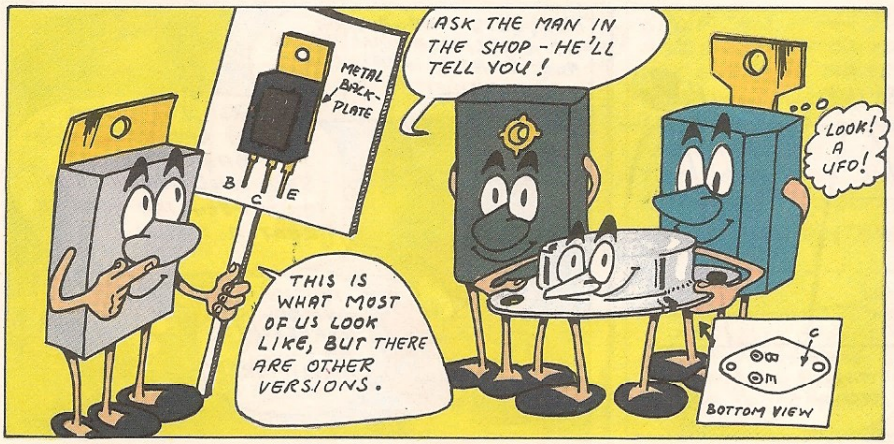
WE MUST ADMIT THAT THE CIRCUIT WE HAVE NOW DOESN'T MAKE THAT MUCH NOISE. WE COULD DO WITH AN 'AMPLIFIER', TO INCREASE THE POWER. LET'S BUILD ONE!

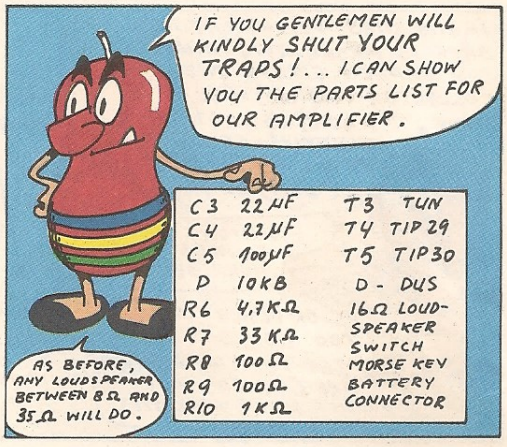

THIS WILL FIT ON THE REST OF THE PRINTED CIRCUIT BOARD.
FIRST, REMOVE THE MORSE KEY AND REPLACE THE SWITCH IN ITS ORIGINAL POSITION.
THEN CUT OFF THE WIRES TO THE LOUDSPEAKER, CLOSE TO THE PRINTED CIRCUIT BOARD.
THE MORSE KEY CONNECTS THE OLD CIRCUIT TO THE NEW PART, AND THE LOUDSPEAKER MOVES TO THE 'OUT PUT'.

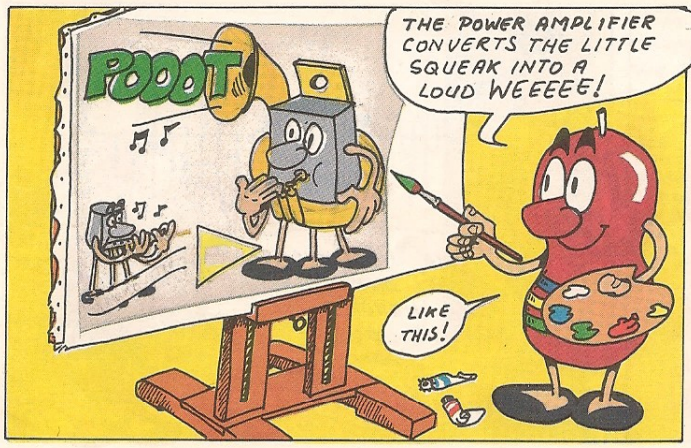

MORSE KEY
22µF-25V
C3
R7
33K
R9
100Ω
R10
1K
DUS
T4
TIP29
T5
100µF
C5
P
10K
22nF
C4
T3
TUN
R6
4.7K
R8
100Ω
16Ω
TIP30
SEE? IT ALL FITS ON THE BOARD!
AMPLIFIER

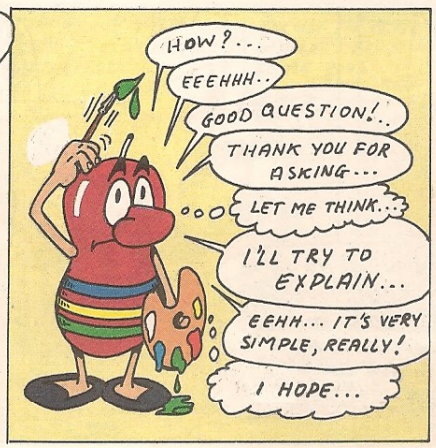

SHOVE OVER, SHRIMP, THE BIG BOYS ARE HERE!
WE'RE THE POWER TRANSISTORS, T4 AND T5
HE'S PNP AND I'M NPN. WE'RE LIKE OTHER TRANSISTORS, BUT MUCH STRONGER!
PNP TIP 30 T5
NPN TIP 29 T4


WHEN WE REALLY GET GOING, WE NEED A 'HEAT-SINK' TO COOL US DOWN! THAT'S WHAT THIS HOLE IS FOR.
BUT DON'T WORRY - WE WON'T NEED IT FOR THIS LITTLE JOB.
MAYBE SOME OTHER TIME.


METAL BACK-PLATE
B C E
ASK THE MAN IN THE SHOP - HE'LL TELL YOU!
LOOK! A UFO!
THIS IS WHAT MOST OF US LOOK LIKE, BUT THERE ARE OTHER VERSIONS.
BOTTOM VIEW


IF YOU GENTLEMEN WILL KINDLY SHUT YOUR TRAPS!... I CAN SHOW YOU THE PARTS LIST FOR OUR AMPLIFIER.
C3 22µF
C4 22µF
C5 100µF
P 10kB
R6 4,7KΩ
R7 33 KΩ
R8 100Ω
R9 100Ω
R10 1KΩ
T3 TUN
T4 TIP29
T5 TIP30
D - DUS
16Ω LOUD-SPEAKER
SWITCH
MORSE KEY
BATTERY CONNECTOR
AS BEFORE, ANY LOUDSPEAKER BETWEEN 8Ω AND 35Ω WILL DO.


POOOT
THE POWER AMPLIFIER CONVERTS THE LITTLE SQUEAK INTO A LOUD WEEEEE!
LIKE THIS!


HOW?...
EEEHHH..
GOOD QUESTION!..
THANK YOU FOR ASKING...
LET ME THINK...
I'LL TRY TO EXPLAIN...
EEHH... IT'S VERY SIMPLE, REALLY!
I HOPE...


OOPS!
PLITCH
4D

MAY I HAVE YOUR ATTENTION! WE WILL NOW DISCUSS 'LINEAR' OPERATION OF A TRANSISTOR'.

FROT FROT

GOSH! THIS STUFF STINKS!!

BLUURK!

OUR AMPLIFIER CONSISTS OF TWO STAGES. FIRST, WE HAVE A VOLTAGE AMPLIFIER.

THE SECOND IS A VOLTAGE FOLLOWER THAT CAN DELIVER MUCH MORE CURRENT THAN THE FIRST STAGE.

LET ME EXPLAIN...

OH NO!!! THIS IS EVEN WORSE!

THE FIRST STAGE COMES FIRST...

...AS YOU MAY HAVE GUESSED. IT'S THIS BIT.

JUST A MINUTE, WHILE I FINISH THIS..

+9V

33K R1

1K R3

OUT

IN

T1

4.7K R2

4.7K R4

TO LEAVE ROOM FOR A MAXIMUM VOLTAGE 'SWING' AT THE OUTPUT, WE MUST 'BIAS' THE COLLECTOR TO +5V. FROM HERE, IT CAN SWING UP 4V AND DOWN 4V. THE VOLTAGE AT THE BASE IS SET BY R1 AND R2, A 'VOLTAGE DIVIDER'. IT IS $\frac{R1}{R1+R2} \times 9V =$ $\frac{4.7}{4.7+33} \times 9 = 1.1V$, APPROXIMATELY.

0.7V BETWEEN BASE AND EMITTER LEAVES 0.4V ACROSS R4.

WET PAINT

9V

0,2mA

4mA

5V

IN

OUT

0,4V

THE SAME CURRENT FLOWS THROUGH R3 AND R4, BUT R3 IS 10 TIMES LARGER. SO THE VOLTAGE ACROSS IT IS 10 TIMES AS MUCH: 4V...

WHICH LEAVES 9V - 4V = 5V AT THE COLLECTOR. JUST WHAT THE DOCTOR ORDERED!

9/4/5

NOW, WHEN WE APPLY AN ALTERNATING VOLTAGE TO THE INPUT, THE OUTPUT WILL SWING AROUND 5V...

POSITIVE PEAK

RATHER CHOPPY SEA, IF I MAY SAY SO!

9V

5V

0

NEGATIVE PEAK

..LIKE THIS!

IF THE 'BIAS' VOLTAGE AT THE BASE IS WRONG, TWO THINGS CAN HAPPEN. EITHER THE COLLECTOR VOLTAGE WILL BE TOO LOW, SO THAT THE NEGATIVE-GOING PEAKS ARE FLATTENED ('CLIPPED')...

...WHICH SOUNDS HORRIBLE...

OR ELSE IT IS TOO HIGH, SO THAT THE POSITIVE PEAKS ARE CLIPPED - WHICH DOESN'T SOUND ANY BETTER.

9V

POSITIVE PEAK

2V

0V.

'CLIPPING'

'MISSING' SECTION

NOW, LET'S TAKE A LOOK AT 'AMPLIFICATION'. AFTER ALL, THAT'S WHAT IT'S ALL ABOUT!

FIRST, I'LL CLIMB DOWN AND EXPLAIN THE BASIC IDEA. AS YOU WILL SEE, IT'S A MOST PECULIAR WAY TO TREAT A SIGNAL!

THIS SYMBOL REPRESENTS AN AMPLIFIER.

I WISH YOU LUCK!

IN

WHEN WE SEND IN A LITTLE POSITIVE SIGNAL, IT WILL COME OUT OF THE AMPLIFIER AS A MUCH BIGGER NEGATIVE SIGNAL. IT IS INVERTED!

THE SAME APPLIES FOR THE NEGATIVE SIGNAL: IT COMES OUT MUCH BIGGER, AND POSITIVE.

THE INPUT SIGNAL COMES OUT AT A MUCH HIGHER LEVEL, BUT IT'S UPSIDE DOWN!

FUNNY ISN'T IT?

HOP!

YD

WE CAN SHOW WHAT GOES 'IN' AND WHAT COMES 'OUT' IN THE SAME DRAWING, LIKE THIS ...

OUT
IN
0V

COMING BACK, NOW, TO OUR TRANSISTOR: THE LITTLE SIGNAL THAT IS APPLIED TO THE BASE WILL ALSO APPEAR AT THE EMITTER. THE VOLTAGE ACROSS RE (100 Ω) VARIES IN STEP, AND SO DOES THE CURRENT... WHICH ALSO FLOWS THROUGH RC! THIS RESISTOR IS 10 TIMES AS LARGE, SO THE SAME CURRENT SWING GIVES A 10 TIMES GREATER VOLTAGE.

AH! IT'S DRY, AT LAST!

1000 RC
IN B C E
100 RE

THE AMPLIFICATION, OR VOLTAGE GAIN, OF THE CIRCUIT IS EQUAL TO THE RATIO BETWEEN RC AND RE. IN THIS CASE:

$G = \frac{Rc}{Re} = \frac{1000}{100} = 10$

DON'T GET MIXED UP! THIS 'G' IS THE VOLTAGE GAIN OF THE CIRCUIT. IT HAS VERY LITTLE TO DO WITH B, THE CURRENT GAIN OF THE TRANSISTOR!

NOW WE CAN PROCEED TO THE SECOND STAGE!

LIFT

THERE ARE TWO TRANSISTORS HERE, AND EACH TAKES CARE OF ITS OWN HALF OF THE SIGNAL.

SIMPLIFIED, IT LOOKS LIKE THIS.

NPN
PNP
IN
OUT

IN
FIRST STAGE
SECOND STAGE
9V
5V
5V
OUT
0V

THIS ISN'T FUNNY!

THEY PROVIDE MORE CURRENT AT THE SAME VOLTAGE, TO INCREASE THE POWER — P=U×I!

WATCH IT! THESE LINES JOIN, IN REALITY. I ONLY SEPARATED THEM TO SHOW WHAT EACH TRANSISTOR DOES!

SINCE THIS STAGE HAS A 'DC BIAS' OF 5V AT E, THE CURRENT WOULD BE ENORMOUS IF THE LOUDSPEAKER WAS CONNECTED THERE. THIS IS WHY I TACKED A CAPACITOR IN BETWEEN: IT BLOCKS THE DIRECT VOLTAGE...

... AND ONLY PASSES THE ALTERNATING (SIGNAL) VOLTAGE TO THE LOUDSPEAKER.

B C E B C

THIS BIT SHAT I'M ADDING HERE...

B E E B

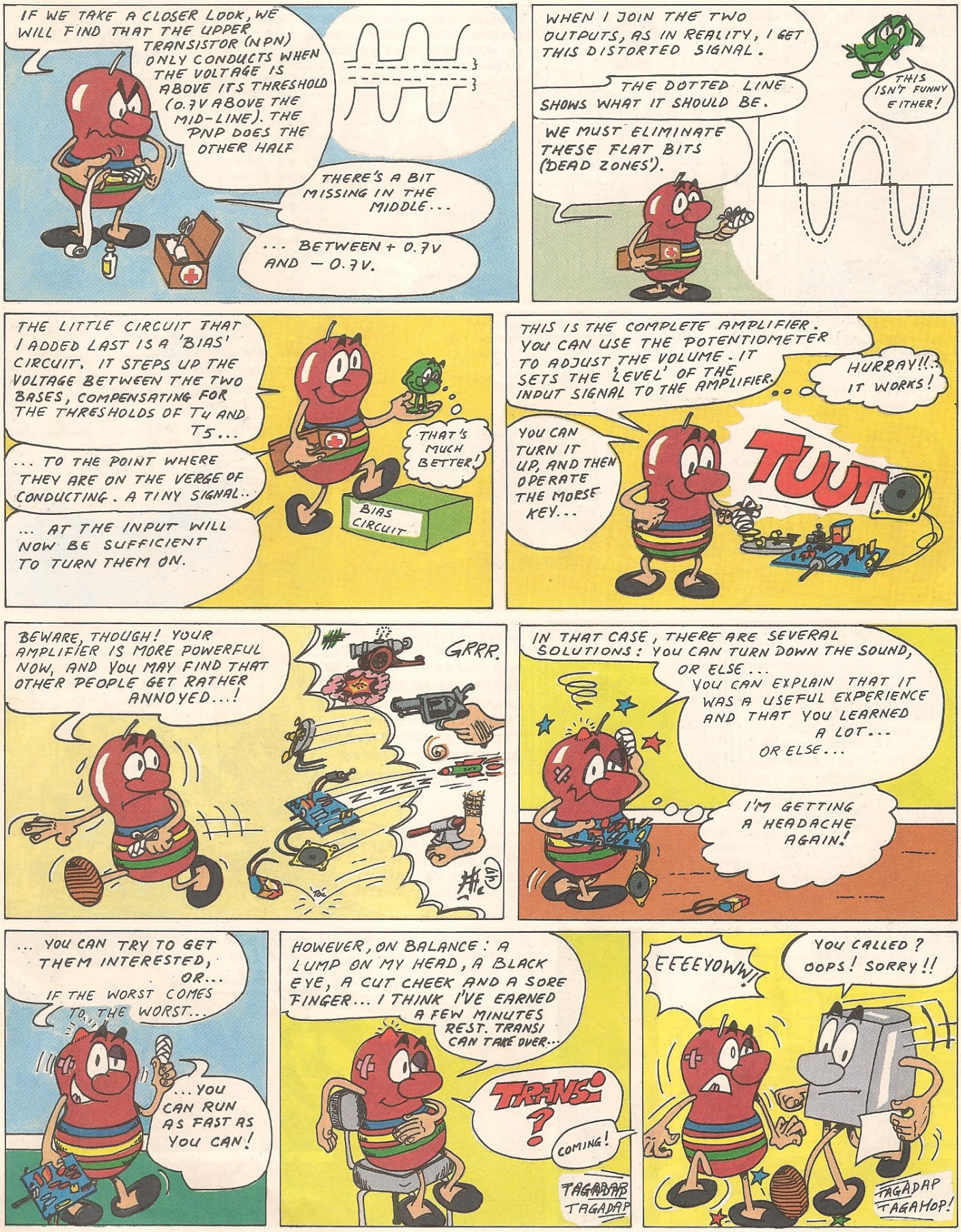
THUM AVE!

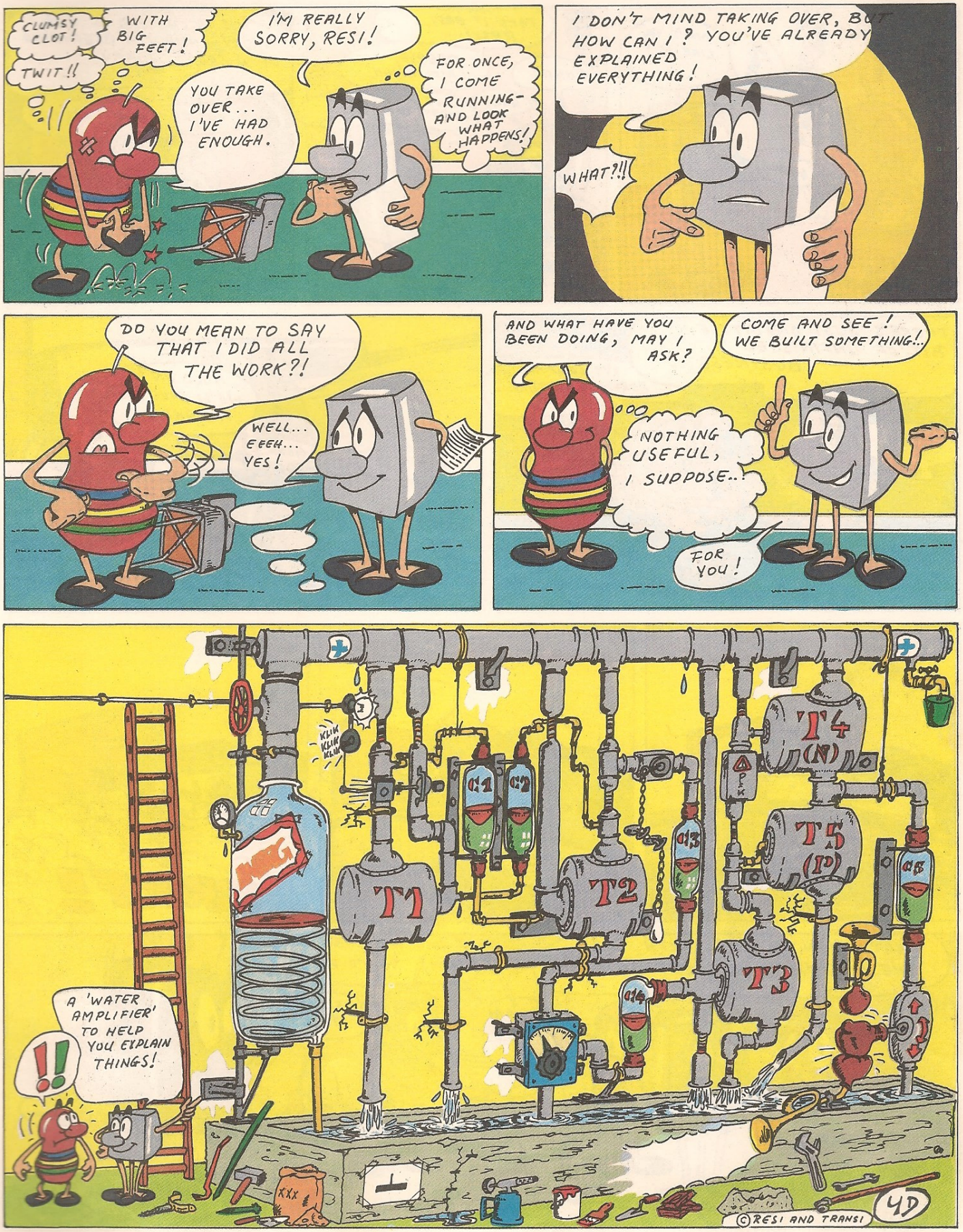
IS INTENDED... OWWW!... TO IMPROVE... OOOH!... THE PERFORMANCE ...OWWAHH... OF THE CIRCUIT.

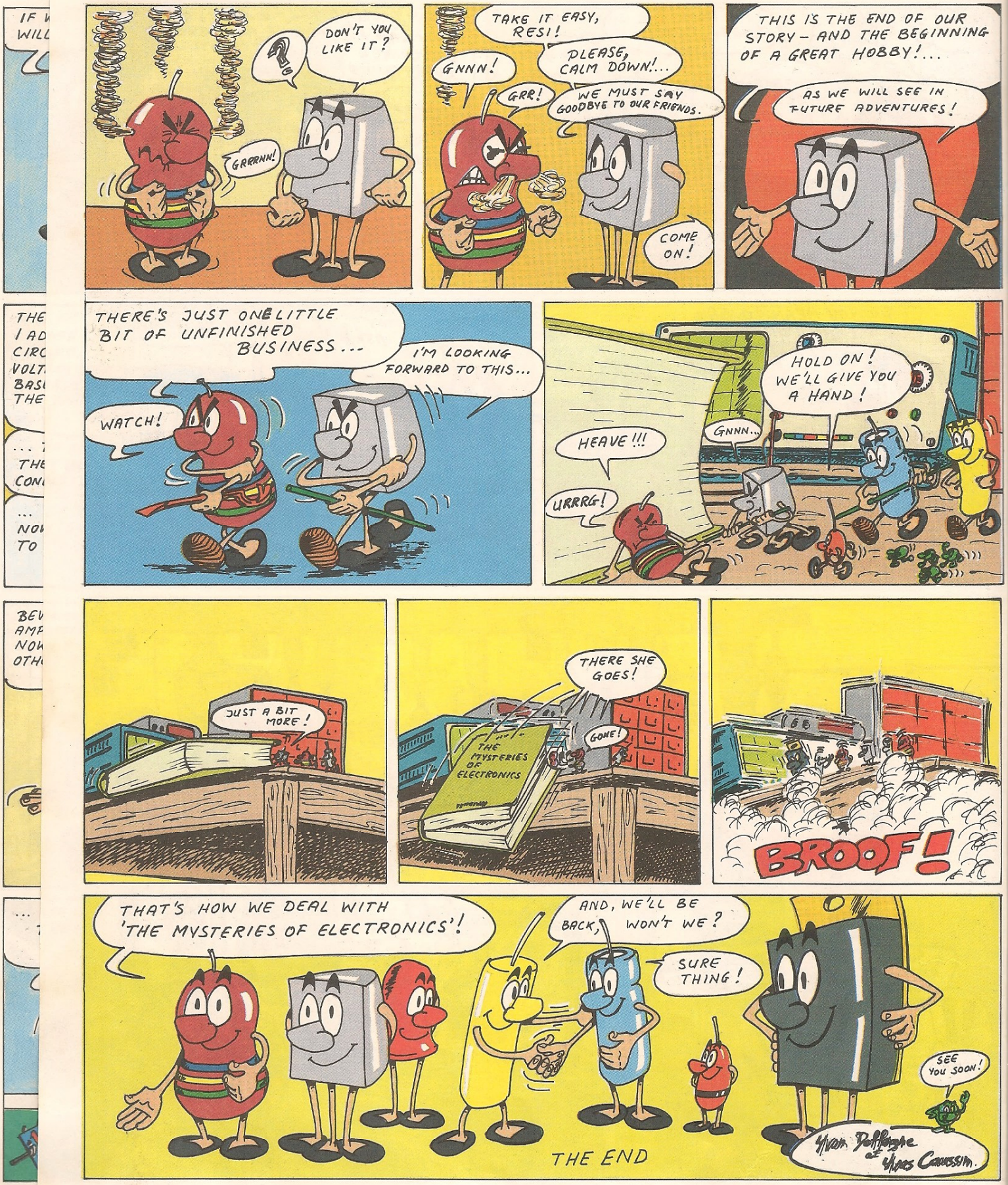
EXCUSE ME A MOMENT, WHILE I GO AND USE SOME BAD LANGUAGE...

Bitr; Biip! Biip!

49


IF WE TAKE A CLOSER LOOK, WE WILL FIND THAT THE UPPER TRANSISTOR (NPN) ONLY CONDUCTS WHEN THE VOLTAGE IS ABOVE ITS THRESHOLD (0.7V ABOVE THE MID-LINE). THE PNP DOES THE OTHER HALF
THERE'S A BIT MISSING IN THE MIDDLE...
... BETWEEN + 0.7V AND − 0.7V.
WHEN I JOIN THE TWO OUTPUTS, AS IN REALITY, I GET THIS DISTORTED SIGNAL.
THE DOTTED LINE SHOWS WHAT IT SHOULD BE.
WE MUST ELIMINATE THESE FLAT BITS ('DEAD ZONES').
THIS ISN'T FUNNY EITHER!
THE LITTLE CIRCUIT THAT I ADDED LAST IS A 'BIAS' CIRCUIT. IT STEPS UP THE VOLTAGE BETWEEN THE TWO BASES, COMPENSATING FOR THE THRESHOLDS OF T4 AND T5...
... TO THE POINT WHERE THEY ARE ON THE VERGE OF CONDUCTING. A TINY SIGNAL...
... AT THE INPUT WILL NOW BE SUFFICIENT TO TURN THEM ON.
THAT'S MUCH BETTER!
BIAS CIRCUIT
THIS IS THE COMPLETE AMPLIFIER. YOU CAN USE THE POTENTIOMETER TO ADJUST THE VOLUME. IT SETS THE 'LEVEL' OF THE INDUT SIGNAL TO THE AMPLIFIER.
HURRAY!!.. IT WORKS!
YOU CAN TURN IT UP, AND THEN OPERATE THE MORSE KEY...
TUUT
BEWARE, THOUGH! YOUR AMPLIFIER IS MORE POWERFUL NOW, AND YOU MAY FIND THAT OTHER PEOPLE GET RATHER ANNOYED...!
GRRR.
IN THAT CASE, THERE ARE SEVERAL SOLUTIONS: YOU CAN TURN DOWN THE SOUND, OR ELSE... YOU CAN EXPLAIN THAT IT WAS A USEFUL EXPERIENCE AND THAT YOU LEARNED A LOT... OR ELSE...
I'M GETTING A HEADACHE AGAIN!
... YOU CAN TRY TO GET THEM INTERESTED, OR... IF THE WORST COMES TO THE WORST...
... YOU CAN RUN AS FAST AS YOU CAN!
HOWEVER, ON BALANCE: A LUMP ON MY HEAD, A BLACK EYE, A CUT CHEEK AND A SORE FINGER... I THINK I'VE EARNED A FEW MINUTES REST. TRANSI CAN TAKE OVER...
TRANSI ?
COMING!
TAGADAP TAGADAP
EEEEYOWW!
YOU CALLED ? OOPS! SORRY !!
TAGADAP TAGAMOP!


CLUMSY CLOT!
TWIT!!
WITH BIG FEET!
I'M REALLY SORRY, RESI!
YOU TAKE OVER... I'VE HAD ENOUGH.
FOR ONCE, I COME RUNNING- AND LOOK WHAT HAPPENS!
I DON'T MIND TAKING OVER, BUT HOW CAN I? YOU'VE ALREADY EXPLAINED EVERYTHING!
WHAT?!!
DO YOU MEAN TO SAY THAT I DID ALL THE WORK?!
WELL... EEEH... YES!
AND WHAT HAVE YOU BEEN DOING, MAY I ASK?
COME AND SEE! WE BUILT SOMETHING!..
NOTHING USEFUL, I SUPPOSE..!
FOR YOU!
A 'WATER AMPLIFIER' TO HELP YOU EXPLAIN THINGS!
!!
T1
T2
T3
T4 (N)
T5 (P)
C1
C2
C3
C4
C5
KLUK KLUK KLUK
PUSH
KXX
©RESI AND TRANS!
YD


DON'T YOU LIKE IT?
GRRRNN!
TAKE IT EASY, RESI!
GNNN!
PLEASE, CALM DOWN!...
GRR!
WE MUST SAY GOODBYE TO OUR FRIENDS.
COME ON!
THIS IS THE END OF OUR STORY - AND THE BEGINNING OF A GREAT HOBBY!...
AS WE WILL SEE IN FUTURE ADVENTURES!
THERE'S JUST ONE LITTLE BIT OF UNFINISHED BUSINESS...
I'M LOOKING FORWARD TO THIS...
WATCH!
HOLD ON! WE'LL GIVE YOU A HAND!
GNNN...
HEAVE !!!
URRRG!
JUST A BIT MORE!
THERE SHE GOES!
GONE!
THE MYSTERIES OF ELECTRONICS
BROOF!
THAT'S HOW WE DEAL WITH 'THE MYSTERIES OF ELECTRONICS'!
AND, WE'LL BE BACK, WON'T WE?
SURE THING!
SEE YOU SOON!
THE END